A SOCIO-TECHNICAL PERSPECTIVE OF VENTILATION PRACTICES IN UK SOCIAL HOUSING WITH WHOLE HOUSE VENTILATION SYSTEMS; DESIGN, EVERYDAY LIFE AND CHANGE

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I, Carolyn Beata Behar confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Signed…………………………………………

Abstract

Whole house ventilation (WHV) systems, currently uncommon in UK housing, have the potential to contribute towards the provision of more sustainable and comfortable new homes. This research adopts a socio-technical approach: 1) to explore how residents of low energy housing with WHV technologies are ventilating their homes, and to understand to what extent their ventilation practices have adapted since living with WHV, and 2) to understand the potential role of various stakeholders in enabling residents to adapt their ventilation practices to coincide with those anticipated by the buildings' designers and required to meet energy performance targets.

Research was conducted at three case study social housing developments, each with a different whole house ventilation system (mechanical extract ventilation, mechanical ventilation with heat recovery and passive stack ventilation). Qualitative methods were used to collected and interpret data from the case studies. These data are explored through the lens of social practice theory to generate insight about how ventilation practices may be constrained and enabled by the physical arrangement of ventilation systems within the home.

The investigation of ventilation routines indicates that individuals do not always use technologies according to the design intent. Furthermore, residents are not always the sole practitioners of ventilation but share this role with a network of actors who appear to have contributed to different elements of observed 'ventilation practices'.

By exploring moments of 'disruption', the study found that while some ventilation activities have adapted since living with WHV, this process of change is slow and unpredictable and not always aligned with designers' intentions for sustainable lifestyles. The thesis highlights the need to consider how occupants' ventilation practices are shaped during the design, construction and handover of new low energy housing to ensure that new homes can enable, and perhaps even encourage, people to live comfortably yet with minimum resource use.

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It is not possible to name the numerous anonymous participants who kindly gave up their time to take part in my research and who patiently tried to answer my somewhat oblique questions on ‘air’. However, their input is very much appreciated and will not be forgotten. I am also thankful to the stakeholders at the three case studies who shared details of post occupancy evaluation and monitoring work which had been carried out previously and on which this thesis seeks to build. Their contributions are noted at the appropriate moments in the text.

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Contents

Table of Figures

Table of Tables

Glossary

Airtightness

Airtightness is a term used to describe a building's permeability, or the '*air leakage rate per hour per square metre of envelope area at the test reference pressure differential of 50 Pascal'* (HM Government, 2013a, p.27). The lower the permeability the more airtight the building is. The units of permeability are $m^3/h.m^2$. Airtightness is measured by pressure testing.

Code for Sustainable Homes

This is a voluntary code introduced in 2006 to try and stimulate the construction of homes that go beyond the minimum regulations. Until recently there were some instances where the Code for Sustainable Homes (CSH) was enforced by local councils in accordance with their planning policy. However, the CSH was withdrawn from planning requirements in 2015.

Design and Build

A 'Design and Build' construction project contract is one where the contractor carries out both the detail design and the construction work. This contrasts a 'traditional' contract where the design process is independent from the construction and a full specification (detail design, schedules, etc.) must be provided by the client before tendering for a contractor.

Fabric first

A fabric first approach to construction is one that focuses on providing a building with a well-insulated building fabric and an airtight envelope. This is prioritised over 'bolt-on' solutions such as on site energy generation from renewable sources as it is believed that the building fabric is harder to replace or remove by subsequent building owners.

Fresh air

In this thesis 'fresh' air refers to external air which is assumed to contain a lower concentration of moisture and pollutants than internal air.

Humidity

Humidity refers to '*the concentration of water vapour in the atmosphere'*. **Absolute humidity** is used to describe the *'mass of water vapour per unit of volume'* and is measured in grams per cubic metre. **Relative humidity (RH)** is the ratio of moisture in air compared to the maximum amount of air that could be held at that temperature, expressed as a percentage (Watt, 2007, p.118).[1]

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[1] It is worth noting that although these terms represent different concepts they are often not used precisely, particularly in everyday language.

Infiltration

The '*uncontrolled exchange of air between inside a building and outside through cracks, porosity and other unintentional openings in a building'* (HM Government, 2010a, p.8).

Post Occupancy Evaluation

Post occupancy evaluation (POE) is the process of rigorously obtaining feedback and information about a building's performance in use, typically occurring following handover and during the first two years of occupation.

Purge ventilation

The '*manually controlled ventilation of rooms or spaces at a relatively high rate to rapidly dilute pollutants and/or water vapour. Purge ventilation may be provided by natural (e.g. an openable window) or mechanical means (e.g. a fan)'* (HM Government, 2010a, p.8).

Ventilation

Ventilation is purpose provided and controlled air intake plus air infiltration.

Ventilation rate

The *'rate at which air within a building is replaced by fresh air'* (EST, 2006, p.4). The ventilation rate in a dwelling is determined by the airtightness of the fabric plus mechanical ventilation systems and their controls plus occupant controlled windows, door and ventilator use. It can be expressed in air changes per hour (ACH), '*the number of times the volume of air within a space is changed in one hour*' (EST, 2006, p.4), or in litres per second (l/s), which is a measure of volumetric air change in time. ACH can be measured using a tracer gas technique, the easiest being carbon dioxide (CO_2). CO_2 can be used to approximate the ventilation rate, where occupancy, and hence CO_2 emission rate, are known. CO_2 and moisture concentration is also used as a proxy for measuring indoor air quality (IAQ), as it is relatively easy to measure.

Participant Pseudonyms

The following pseudonyms are used throughout the text (especially Chapters 5-8), to maintain informants' anonymity whilst preserving their human character. Readers are advised to refer to a copy of this page for reference.[2]

Participants	Pseudonym (code)	Case	Ventilation type	Profession / role	Dwelling code
Residents	Ali	A	MEV		A0
	Sabeen	A	MEV		A1
	Fara	A	MEV		A2
	Karen	A	MEV		A3
	Pamela	A	MEV		A4
	Betty	B	MVHR		B0
	Paul	B	MVHR		B1
	Dan	B	MVHR		B2
	Anthony	B	MVHR		B3
	Steve	B	MVHR		B4
	Luke	B	MVHR		B5
	Carla	C	PSV		C0
	Sarah	C	PSV		C1
	Maria	C	PSV		C2
	Joy	C	PSV		C3
Non-residents	Christopher	A	MEV	Project Architect /Director	
	Richard	A	MEV	POE Consultant	
	Eddie	A	MEV	RSL Sustainability Manager	
	Yvonne	A	MEV	RSL Sustainability Officer	
	Mark	B	MVHR	Project Architect / Planning Stage	
	Dominic	B	MVHR	Project Architect / Construction Stage	
	Stuart	B	MVHR	Contractor - Design & Planning Executive	
	Janet	B	MVHR	RSL Housing Officer	
	Brian	B	MVHR	RSL Project Manager	
	Helen	C	PSV	Architect / Partner	
	Martin	C	PSV	Contractor / Director	
	Michael	C	PSV	RSL Technical Manager	
	Douglas	C	PSV	RSL Business Manager	

[2] This figure is also reproduced at the start of the Appendix volume.

Abbreviations and Acronyms

ACH: Air changes per hour (air change rate)

ADF: Building Regulations Approved Document F

ADL: Building Regulations Approved Document L

AHU: Air handling unit

BCB: Building Control Body

BREHOMES: Building Research Establishment Housing Model for Energy Studies

CCA: Climate Change Act

CO_2: Carbon dioxide

CSH: Code for Sustainable Homes (Levels 1 – 6, i.e. CSH3)

DER: Dwelling Emission Rate

DFEE: Dwelling Fabric Energy Efficiency

EPBD: Energy Performance of Buildings Directive

FEES: Fabric Energy Efficiency Standard

FHL: Fabric heat loss

FSC: Forest Stewardship Council

GHG: Greenhouse gas

HE: Heat exchanger

HA: Housing association

HRV: Heat recovery ventilation

IAQ: Indoor air quality

LEH: Low energy housing

MEV: Mechanical extract ventilation

MV: Mechanical ventilation

MVHR: Mechanical ventilation with heat recovery

NOx: Mono-nitrogen oxides (Nitric oxide and nitrogen dioxide)

NV: Natural ventilation

O&M: Operation and maintenance

PM: Particulate matter

POE: Post occupancy evaluation

PSV: Passive stack ventilation

PVC: Polyvinyl chloride

REVHA: Federation of European Heating, Ventilation and Air Conditioning Associations

RH: Relative humidity

RIBA: Royal Institute of British Architects

RSL: Registered social landlord

SAP: Standard Assessment Procedure

SPF: Specific fan power

STS: Science and technology studies

TER: Target Emission Rate

TFEE: Target Fabric Energy Efficiency

TPB: Theory of Planned Behaviour

TRA: Theory of Reasoned Action

TRV: Thermostatic radiator valve

UK: United Kingdom

VHL: Ventilation heat loss

VOC: Volatile organic compounds

WHV: Whole house ventilation

Chapter 1: Introduction

1.1. Research context

1.1.1. Living with new ventilation technologies in low energy housing

New technologies are being introduced into low energy housing (LEH)[3] to provide controlled ventilation for the health and comfort of the occupants and to protect the building fabric from moisture, whilst simultaneously maintaining an energy efficient and airtight building envelope (Johnston et al., 2005). This group of technologies, known as 'whole-house' ventilation (WHV) systems, are relatively uncommon in UK housing, where most people are accustomed to living in homes with a draughty building fabric. These homes are typified by air bricks, fireplaces and loose-fitting windows: over half the UK's housing stock was built before 1965 (Palmer and Cooper, 2013), which was when the UK building regulations were introduced (see Table 8, p.53).

Although innovative WHV systems have the potential to contribute towards the provision of more sustainable and comfortable new housing,[4] this thesis challenges the assumption that simply introducing a new technology will guarantee a reduction in energy consumption. Shove et al. (2012) argue that this kind of assumption is a common mistake within the techno-economic paradigm which frames the challenges of technology transfer around overcoming certain social or non-technical barriers (Figure 1).

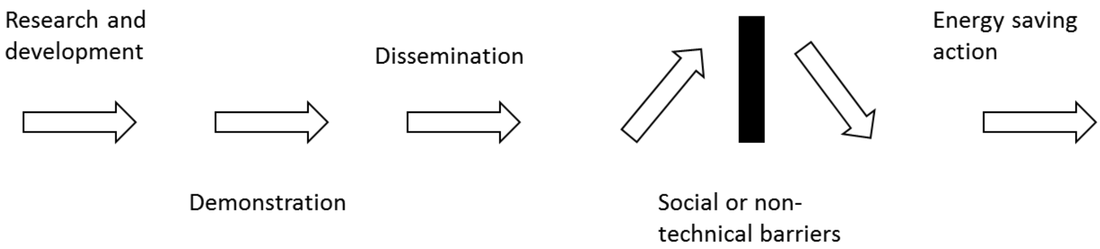

Figure 1: A techno-economic mode of technology transfer[5]

Instead, to fully realise the potential of WHV in terms of energy and indoor air quality (IAQ), inhabitants will need to change the way they ventilate their homes too; technologies by themselves will not create this adjustment. If people do not change the way they ventilate, but continue to use traditional strategies such as opening windows, LEHs may use more energy

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[3] In this thesis, LEH refers to dwellings which have been designed to use less energy than conventional, older homes or typical contemporary homes. It does not refer to measured energy consumption.
[4] These systems and their potential benefits are described in greater detail in sections 2.1.4 and 2.1.5.
[5] Diagram adapted from Shove et al. (2012), p.62.

than expected, contributing to the performance gap between designed and actual energy use (Fabi et al., 2012).

This thesis sets out to explore how residents of LEH with WHV are ventilating their homes, and to understand to what extent the design of these homes helps residents adapt to a new type of ventilation. Social practice theory (SPT)[6] is used to frame an empirical study of ventilation design and use, which investigates how, as people go about their daily routines, their lifestyles intersect with the different components of ventilation systems.

1.2. Research aims

1.2.1. Research questions

This thesis aims to investigate the previously underexplored topic of domestic ventilation practices in LEH which has been designed to use WHV. The thesis explores how residents of LEH with WHV technologies are ventilating their homes and to what extent their ventilation practices have adapted since living with WHV. The research also seeks to understand the potential role of various stakeholders, including architects, contractors and registered social landlords (RSLs), in enabling residents to adapt their ventilation practices to coincide with those which were imagined by the buildings' designers and which are required to meet current energy performance targets.

A theoretical framework is adopted, based on two scholars' formulation of SPT (Schatzki, 2002, Gram-Hanssen, 2011) (see 3.4.1).

The following four questions are addressed in this thesis

> *Q1 How does the design and construction of homes with WHV systems create a physical arrangement which can constrain and enable residents' ventilation practices?*
>
> *Q2: How does the process of inhabiting a home conflict with residents performing ventilation as the designers intended and anticipated?*
>
> *Q3: How are people who live with WHV ventilating their homes?*
>
> *Q4: How might interventions be constructed by different actors to help residents use ventilation as intended?*

These questions are listed in the order they are addressed in the thesis, which follows an approximate chronological progression from the design and construction phases of a housing project, to its routine occupation by residents and, finally, considering post occupancy

[6] SPT can be used to study energy consumption as a 'by-product' of our everyday lifestyles. The key theorists and concepts, as well as its application to energy demand research are introduced in the Literature Review and explored in more detail throughout the thesis.

interventions which may disrupt and change ventilation practices. The physical context of dwellings with WHV is explored first in order to place the occupant enactment of practice in context, and to introduce the three case study housing developments from where data were collected. The rationale for these questions is discussed further in section 3.4.2.

1.2.2. Research scope

This thesis adopts a case study approach to address the research questions outlined above. Three social housing developments, completed between 2005 and 2011 were selected to explore the three WHV strategies which are detailed in Approved Document Part F (ADF) of the Building Regulations (HM Government, 2010a). These are passive stack ventilation (PSV), continuous mechanical extract ventilation (MEV), and mechanical ventilation with heat recovery (MVHR). The rationale for using case studies is discussed in section 4.3.

Qualitative research methods were used, comprising 28 in depth interviews with residents, architects, contractors and RSLs, alongside analysis of design, construction and handover documentation and photographs taken during walkthroughs with residents in their homes. The rationale for selecting a qualitative research methodology is discussed in section 4.2.4 and the research methods used to collect and analyse data are presented in section 4.4. The case studies themselves are introduced in Chapter 5 with supplementary material provided in Appendix C.

1.3. Thesis Structure

Table 1 presents the structure of the thesis by outlining the scope of each chapter:

Table 1: Thesis structure

Chapter	Title	Purpose
1	Introduction	Introduces the research aims and outlines the thesis structure.
2	Ventilation strategies in low energy housing	Locates the work within the context of evolving housing design and ventilation technologies. Outlines the key environmental and regulatory challenges facing the current ventilation arrangement.
3	Researching ventilation practices	Positions the research within its theoretical framework. Identifies a knowledge gap and clarifies the research questions which guide the empirical investigations.
4	Methodology and methods	Sets out methodological principles which guide this interdisciplinary research. Presents the rationale for the selection of methods and use of case studies.
5	The physical arrangement of homes with whole house ventilation	Addresses Q1 and Q2.

6	Ventilation practices as complex bundles; Routines, lifestyles and past experiences	Addresses Q3.
7	Disruptions for change	Addresses Q4.
8	Discussion and conclusion	Discussion integrates the findings of previous chapters in relation to the research questions and proposes recommendations for practice, policy and research. Reflects on methodological and theoretical limitations and suggests directions for future work. Conclusion summarises the key findings and contributions of the research.

Chapter 2: Ventilation Strategies in Low Energy Housing

This chapter outlines some of the challenges surrounding current domestic ventilation arrangements. It argues that residents are faced with the need to adjust their lifestyles to not only one new ventilation technology but potentially three or more different types, some parts of which even the technical community struggle to understand.

Section 2.1 introduces domestic ventilation in low energy housing (LEH) as a complex balancing act between health, energy and comfort, by drawing upon academic literature as well as industry reports and government regulations. It also introduces the building regulations which relate to ventilation and describes the four whole house ventilation (WHV) systems which are 'approved' by these regulations. Section 2.2 contextualises today's innovative WHV systems in relation to the dynamic co-evolution of UK housing design, domestic ventilation and society, across five historical periods. Finally, section 2.3 discusses the implications of the current arrangement on possible ventilation practices and argues that since the social and technical aspects of ventilation cannot easily be separated from one another, a socio-technical approach to understanding this phenomenon is justified. This provides the context for discussing how practices may change and under what circumstances (Chapter 6 and Chapter 7).

2.1. Domestic ventilation today: balancing health, energy and comfort

This section sets out the three key challenges associated with ventilating low energy homes, namely, providing healthy air, conserving heat energy and maintaining a comfortable thermal environment. The challenge facing housing designers and constructors is meeting all three requirements simultaneously. This can only be achieved by successfully negotiating the tension between the need to maintain a steady rate of airflow at the same time as trying to minimise both fabric and ventilative heat losses.

2.1.1. Healthy air

Indoor air quality and health

The purpose of ventilation in buildings in relation to human health is to dilute moisture and other pollutants which may harm the health of the occupants, either directly, or indirectly through the growth of mould and dust mites. In contemporary homes, stale air contains a complex mixture of external pollutants which have entered the building, combined with pollutants generated indoors (Diette et al., 2008). A list of some of the most commonly occurring pollutants, their sources and potential health risks is presented in Table 2 (compiled from Fehlmann and Wanner (1993), Crump (2004), Davies et al. (2004), and NHBC and BRE (2009)).

Table 2: Pollutants commonly found in dwellings

Pollutant	Source (internal)	Source (external)	Health impact
Mould spores	Mould growth on high RH surfaces	External mould growth	Exacerbate asthma
House dust mite faeces	House dust mites		Exacerbate asthma, eczema, allergic reactions
Nitric oxide and nitrogen dioxide (NOx)	Incomplete cooking combustion	Motor vehicles	Respiratory and cardiovascular conditions
Odour	Pets and humans		
Carbon monoxide	Incomplete combustion from stoves, boilers etc.		Carbon monoxide poisoning
Radon		Naturally occurring in certain geological conditions	Lung cancer
Tobacco	Smoking cigarettes		Respiratory and cardiovascular conditions, lung cancer
Particulate matter (PM)	Dust	Motor vehicles, dust from agriculture, building works	Respiratory and cardiovascular conditions, premature death
Pollen		Flowering plants	Allergies (hay fever)
Moisture - may condense in low temperatures causing damp	Showering, laundry, water appliances, pipes	Broken guttering, water ingress	Exacerbate asthma, allergies and respiratory conditions
Volatile organic compounds (VOCs)[7]	Paint, formaldehyde, household cleaning products		Known carcinogens
Ozone		Created by chemical reactions between NOx and VOCs in sunlight	Exacerbate asthma and other respiratory conditions

There are health risks associated with higher exposure to these pollutants. For example, a meta-analysis and review by Fisk et al. (2007) concluded that *'building dampness and mold are associated with approximately 30–50% increases in a variety of respiratory and asthma-related health outcomes'* (p.284). The presence of mould in homes is associated with high relative humidity (RH) and low temperatures, which can cause condensation and lead to moisture and damp problems. House dust mites are more prevalent in poorly ventilated spaces with a high

[7] VOCs are released from substances which have a low boiling point and therefore evaporate at room temperature; e.g. formaldehyde found in paint fumes.

RH. Their presence can exacerbate existing asthma symptoms and may also lead to eczema and other allergic reactions (Davies et al., 2004). Radon, a naturally occurring radioactive substance, is thought to be the main cause of lung cancer in non-smokers (Hemsath et al., 2012). Nitrogen dioxide is a by-product of combustion of fossil fuels and is found in greater outdoor concentrations in urban areas. It is linked to a number of respiratory and cardiovascular conditions (Brunekreef and Holgate). The risks associated with indoor air quality (IAQ) and health are generally even greater in children (Berry et al., 1996, Götschi et al., 2008). A well-ventilated space is important so that concentrations of moisture and pollutants are reduced and the associated health risks minimised.

Regulating for indoor air quality

The requirement for ventilation in all building types is outlined in Approved Document Part F of the Building Regulations (ADF).[8] Regulation F1(1) states that *'there shall be adequate means of ventilation provided for people in the building'* and F1(2) states that *'fixed systems for mechanical ventilation and any associated controls must be commissioned by testing and adjusted as necessary'* (HM Government, 2010a, p.5). The Approved documents detail how the regulations can be met, for example if minimum air flow rates are provided, as detailed in Table 3 and Table 4.[9] There is no maximum ventilation rate specified in ADF. However, keeping ventilation rates as low as possible makes it easier to comply with Part L of the Building Regulations (ADL), which is concerned with the conservation of fuel and power (see 2.1.2).

Table 3: Minimum extract and ventilation rates from ADF p.19

Extract ventilation rates			
Room	**Intermittent extract**	**Continuous extract**	
	Minimum rate	**Minimum high rate**	**Minimum low rate**
Kitchen	30 l/s beside hob or 60 l/s elsewhere	13 l/s	Total extract rate must be at least the whole house ventilation rate described below
Utility room	30 l/s	8 l/s	
Bathroom	15 l/s	8 l/s	
WC	6 l/s	6 l/s	

Table 4: Minimum whole dwelling ventilation rates from ADF p.19

Whole dwelling ventilation rates					
Number of bedrooms	1	2	3	4	5
Whole dwelling ventilation rate	13 l/s	17 l/s	21 l/s	25 l/s	29 l/s

To meet requirement F1(1) the document recommends a ventilation strategy based on the following three types of ventilation:

[8] Unless otherwise mentioned ADF refers to the latest, 2010, version of the document, which was amended in 2013 (see Table 8 on p.48).

[9] An alternative, performance-based means of compliance for dwellings is set out in Appendix A, which lists maximum exposure levels for nitrogen dioxide and carbon monoxide as well as a moisture criterion of '*no visible mould'* (p.43).

Extract ventilation: This is required to remove water vapour and pollutants from areas where they are generated (kitchens, utility rooms and bathrooms), and can be either intermittent or continuous.

Whole dwelling ventilation: Background ventilation is required to maintain a continuous air exchange to remove residual pollutants and provide ‘fresh’ air to habitable rooms (living rooms, bedrooms).

Purge ventilation: A rapid rate of ventilation (minimum 4 air changes per hour (ACH)) for occasional situations where a greater concentration of pollutants is released at once.

Additional references to ventilation and IAQ are made in Approved Document Part C (ADC) which is concerned with “Site preparation and resistance to contaminants and moisture” (HM Government, 2013b) and Approved Document Part J (ADJ) which provides guidance relating to “Combustion appliances and fuel storage systems” (HM Government, 2010b). ADC includes a section about radon protection measures in ‘*at risk’* homes (p.21).[10] ADJ focuses on preventing fire and reducing the risk of carbon monoxide poisoning.

2.1.2. Saving energy

Energy demand context

In the UK, space heating accounts for over 60% of a dwelling’s energy use and ventilation heat loss accounts for approximately 20% of dwelling’s heat loss (Palmer and Cooper, 2013, p.35).[11] Around a third of all global greenhouse gas (GHG) emissions are as a result of burning fossil fuels to service buildings (IEA, 2011). Existing dwellings account for over 25% of CO_2 emissions in the UK (Palmer and Cooper, 2013), or 29% of total energy consumption (DECC, 2014, p.19), through fulfilling people’s need for hot water, space heating, lighting and through appliance use. The UK Climate Change Act (DECC, 2008) sets a legally binding target of at least an 80% cut in greenhouse gas emissions from 1990 levels by 2050. This action is considered necessary for the UK to play its part in holding the increase in global temperature below 2°C. The 20-20-20 EU legislation objectives for 2020 require a 20% reduction in EU greenhouse gas emissions from 1990 level and a 20% improvement in the EU's energy efficiency (European Commission, 2014).

To meet these targets, new homes in the UK need to be built to increasingly stringent energy performance targets. The Government have been attempting to promote a transition to *‘zero*

[10] Risk levels are based on geographical location.
[11] Based on modelled values of the housing stock using BREHOMES, the Building Research Establishment Housing Model for Energy Studies. The share of total energy used by heating in dwellings increased from 58% to 62% between 1970 and 1990.

carbon' homes through implementation of the Zero Carbon Standard from 2016 (ZCH, 2014).[12] However, at time of editing (September 2015) the Government have just withdrawn the 2016 zero carbon homes target and the future direction of changes to the building regulations are unclear (HM Treasury, 2015). However, the UK is still legally bound to a near zero energy target by 2020 according to the Energy Performance of Buildings Directive (EPBD).

Fabric efficiency and airtightness

An effective way to reduce the energy consumption associated with dwellings which are located in cooler climates with a long heating season is to improve the efficiency of the building fabric, and to reduce the permeability of the building envelope (by increasing airtightness), so that less heat is lost to the outside air. Approved Document Part L1A (ADL1A)[13] sets out the requirements of the building regulations for the "conservation of fuel and power in new dwellings" as follows:

> *'**L1** Reasonable provision shall be made for the conservation of fuel and power in buildings by: (a) limiting heat gains and losses - (i) through thermal elements and other parts of the building fabric; and (ii) from pipes, ducts and vessels used for space heating, space cooling and hot water services; (b) providing fixed building services which - (i) are energy efficient; (ii) have effective controls; and (iii) are commissioned by testing and adjusting as necessary to ensure they use no more fuel and power than is reasonable in the circumstances' (HM Government, 2013a, p.3).*

To comply with ADL1, the Dwelling Emission Rate (DER) must not exceed the Target Emission Rate (TER).[14] A second requirement, new to the 2013 regulations, is that the calculated Dwelling Fabric Energy Efficiency (DFEE) rate must not be greater than the Target Fabric Energy Efficiency (TFEE) rate.[15]

As well as proving compliance with required emission targets, the regulations state that the dwelling owner be provided with information about the operation and maintenance of fixed building services (heating, hot water and ventilation) so that the building uses '*no more fuel and power than is reasonable in the circumstances'* (HM Government, 2013a, p.24). A suggestion for meeting this requirement is to issue occupants with operating and maintenance instructions which explain the design principles and operation of any fixed services, as well as providing a copy of compliance data and product manuals.

To comply with ADL1, the TER and TFEE must be calculated using the Standard Assessment Procedure (SAP) 2012 (HM Government, 2013a). SAP is a Government approved methodology

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[12] The exact requirements of this standard are still being decided; however, it is likely to allow compliance through a combination of fabric energy efficiency, on site low/zero carbon heat and power and off site on site low/zero carbon heat and power.
[13] Unless otherwise mentioned ADL refers to the 2013 version of the document.
[14] DER and TER are calculated CO_2 emissions, described in $kgCO_2/m^2$/year.
[15] DFEE and TFEE are the energy normally required to comfortably heat the dwelling in kwh/m^2/year.

for assessing the energy performance of new dwellings. The calculation is based on a *'notional dwelling of the same size and shape as the actual dwelling'* (HM Government, 2013a, p.6).[16] The only testing of a dwelling's building fabric that is required by ADL is air pressure testing. Once the building is erected, pressure testing should be undertaken to ensure that *'as built'* permeability does not exceed 10 $m^3/h/m^2$ @50Pa and that the DER and DFEE calculated using the measured permeability do not exceed the TER and TFEE rate respectively (HM Government, 2013a p.20).[17]

2.1.3. Maintaining thermal comfort

Thermal comfort can be defined as *'that condition of mind which expresses satisfaction with the thermal environment'* (ASHRAE, 2004). Temperature is an important part of thermal comfort and ventilation is a key mechanism of controlling temperature where there is a difference between inside and outside. Although the precise relationship between ventilation and thermal comfort has been disputed (e.g. Fanger, 1970, Humphreys and Nicol, 1998, Nicol et al., 1999), it is now accepted that temperature (air and radiant), air velocity and relative humidity are related to perception of thermal comfort and discomfort and that the ability to take action to make changes to one's environment may increase perceived comfort (Brager and de Dear, 1998).

The movement of air has a cooling affect, which, depending on other factors, may be experienced by humans as either an uncomfortable draught, a pleasant breeze or anything in-between (CIBSE, 2007). Unpleasant draughts can be minimised by increasing airtightness in a dwelling, although there are currently no regulations pertaining to thermal comfort in buildings (HM Government, 2010a, p.14). Instead, regulations are concerned with protecting people from invisible health risks or mandating unwanted features which would otherwise be neglected. However, a fundamental purpose of constructing buildings is to provide comfortable and useful spaces for people to inhabit; therefore, thermal comfort is an important component of building design. Thermal comfort is also indirectly accounted for in SAP, which assumes a certain level of comfort in its calculation.

Ventilation is also used by people to maintain a thermally pleasant internal environment. For example, during summer, cooling can be provided by opening the windows or using an electric fan, both of which cause air movement. Night purge ventilation can be used to alleviate periods of overheating by allowing cold air to enter the building at night, so that the coolth is stored in

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[16] Compliance with SAP is calculated and demonstrated using a worksheet and data tables (see Appendix E, p365).

[17] Developments of only one or two dwellings can choose to use a value of 15 $m^3/h/m^2$ @50Pa in the SAP calculation instead of carrying out a pressure test. For larger schemes a sample may be tested instead.

the thermal mass of the building fabric and released during the following day. This technique can reduce peak temperatures and consequent comfort cooling loads (CIBSE, 2005).[18]

The potential for using ventilation to moderate thermal comfort during summer is discussed in ADL1, which states that solar gain can be reduced through '*an appropriate combination of window size and orientation, solar protection through shading and other solar control measures, ventilation (day and night) and high thermal capacity'* (HM Government, 2010c, section 4.25).

2.1.4. Challenges relating to ventilation in low energy housing

Balancing health, energy and comfort

The previous sections discussed the challenge of simultaneously providing good IAQ, conserving heat energy and maintaining a comfortable thermal environment. To achieve this balance, a dwelling must maintain a steady rate of airflow at the same time as minimising heat losses through the fabric and ventilation. This tension is exemplified in ADF, which makes explicit the difference between air infiltration and purpose-provided ventilation, favouring the latter over the former. This tension is made more complicated by the fact that many pollutants are occupant generated and their concentration may vary between households with differing numbers of occupants or with different lifestyles.

In theory, a well-designed and fully functioning dwelling should admit just the right amount of air to meet the ventilation requirements, but no more than this. The reality of achieving this exact balance is challenging. Although in theory *'the designer has the freedom to use whatever ventilation provisions suit a particular building'* (HM Government, 2010a p.15), in practice most new homes use one of four approved ventilation strategies which can fulfil the requirements of both ADL1 and ADF. These are outlined in the "Domestic Ventilation Compliance Guide" (HM Government, 2010d). The systems are: 1) background ventilation with intermittent extract fans (IEV); 2) passive stack ventilation (PSV); 3) continuous mechanical extract ventilation (MEV); and 4) mechanical ventilation with heat recovery (MVHR). Each of these systems is described and discussed in more detail in section 2.1.5.

The Domestic Ventilation Compliance Guide replaced Appendices D and E of the 2006 edition of ADF. It was introduced specifically to ensure that new homes provide *'adequate ventilation while minimising energy use and environmental problems such as noise and thermal discomfort'* (HM Government, 2006 p.5). The document references three statutory requirements which must be met so that compliance with ADF and ADL1 can be demonstrated. First of all, commissioning

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[18] Night purge ventilation can be an effective means of reducing overheating during hot summer days. To maximise its effectiveness, windows should be kept closed and shaded during the day and then opened up at night time when it is cooler. The hot air is then 'purged' from the house and then replaced with cool night air, so that building fabric is cooled over the course of the night. The following day the windows are kept closed again so that, if the house is sufficiently well insulated, internal temperatures remain lower than external ones.

must be carried out in accordance with an approved procedure (ADF); secondly, airflow rates must be measured and reported upon completion of any new dwelling with mechanical ventilation systems (ADF); thirdly, information about the operation and maintenance of the ventilation system must be provided to dwelling owners or occupiers (ADL1).

The three stages of commissioning are visual inspection, airflow balancing and airflow measurement testing. The requirement for each system is shown in Table 5. Detailed instructions for each step are outlined in the guide. Measured airflow rates should be compared to design specifications; compliance is achieved if the airflow rate is greater than or equal to design targets. This information must be presented to the Building Control Body (BCB) as proof of commissioning and testing.

Table 5: Commissioning procedures for ventilation systems

System	Visual inspection	Airflow balancing	Airflow measurement
1: Intermittent Extract	Yes	No	Yes
2: PSV	Yes	No	No
3: MEV	Yes	Yes	Yes
4: MVHR	Yes	Yes	Yes

Section 4 of the guide is concerned with the completion and handover of the system. An ‘Operation and Maintenance (O&M) Manual’ must be provided to the end user, containing at least the information set out in Table 6, below. In addition, a signed copy of the inspection checklist and airflow measurement test sheet should be included with the manual.

Table 6: Handover information to be included in Operation and Maintenance Manual

Ventilation documentation for end user
Design statement
Manufacturer’s contact details
Location and setting of automatic controls
Location and use of boost settings for MV
Details of air inlets for background ventilation
Instructions for cleaning and maintenance
Location of filters or how to access ducts
Recalibration / sensors

Overheating

Overheating can be an unintended consequence of increasing airtightness and reducing ventilation rates in LEH. The term overheating refers to excessively hot internal temperatures. This is most likely to occur at times when outdoor temperatures exceed comfortable indoor temperatures. There are currently no definitive criteria for defining when domestic overheating occurs; however, it is agreed that excessive exposure to very high temperatures can cause serious health problems (Bone et al., 2010, NHBC, 2012, NHS, 2014). As homes become more airtight, concerns have been raised that dwellings will contain a higher concentration of pollutants, such as VOCs, radon and moisture, which can be harmful to people (Davies and

Oreszczyn, 2012, Shrubsole et al., 2014). Another danger is the risk of overheating in LEH, due to more efficient building envelopes and lower air change rates

Appendix P of SAP 2012 provides a method for calculating the risk of overheating during hot weather (June, July and August) as either not significant, slight, medium or high (BRE and DECC, 2014, p.102). This calculation takes into account dwelling type, window opening potential and solar gains. It is assumed that upstairs windows are left fully opened all night and that downstairs windows are opened half the time. Based on these assumptions the effective air change rate is expected to rise to enable ventilative cooling (Table 7). It is also assumed that curtains are closed during daylight hours and a shading factor is applied based on the colour and type of curtain or shutter. However, Appendix P has no impact on DER or SAP rating and is not mandatory: the '*space cooling requirement'* must be calculated only in those dwellings with fixed air-conditioning systems (BRE and DECC, 2014, p.31).

Table 7: Effective air change rates during summer assumed in SAP[19]

Window opening	**Effective ACH**			
	Trickle vents only	Windows slightly open (50 mm)	Windows open half the time	Windows fully open
Single storey dwelling; cross ventilation possible	0.1	0.8	3	6
Single storey dwelling; cross ventilation not possible	0.1	0.5	2	4
Dwelling of two or more storeys windows open upstairs and downstairs; Cross ventilation possible	0.2	1	4	8
Dwelling of two or more storeys window open upstairs and downstairs; Cross ventilation not possible	0.1	0.6	2.5	8

No other references are made to window opening in the technical guidance document (BRE and DECC, 2014). SAP 2012 assumes a throughput of 0.5 ACH through naturally and mechanically ventilated dwellings. Therefore it may be concluded that, in mechanically ventilated homes, SAP assumes that windows are closed at all times during the heating season.

The CIBSE overheating risk criteria were revised in 2013 following recommendations of the CIBSE Overheating Task Force (CIBSE, 2013). Whereas previously, a building was defined as overheating if temperatures exceeded 28% for more than 1% of the time (CIBSE, 2007), the new definition, for buildings which are not mechanically cooled, requires calculation of three

[19] Reproduced from BRE and DECC (2014, p.102).

criterion, based on *'hours of exceedance'*, '*daily weighted exceedance'* and the *'upper limit temperature'* (CIBSE, 2013, p13-14).

If summer temperatures increase as predicted, due to the effects of global warming, this issue will become increasingly pertinent: if people are not able to modify their environment to maintain comfortable temperatures during hot weather there may be a significant increase in use of active cooling, which could increase CO_2 emissions. The risk of increased use of air conditioning in very airtight dwellings with mechanical ventilation has been noted by Liddament (2011).

2.1.5. Four 'approved' systems for compliance with ADF

The four approved systems which are outlined in ADF 2010 and the 201o Domestic Ventilation Compliance Guide are discussed below. Each system is described in terms of its designed operation and physical configuration. The images in this section are adapted from ADF and are intended as illustrative diagrams and are not accurate representations of built form. The historical development of the four systems is discussed in section 2.2.4.

System 1: Background ventilators and intermittent extract fans

System 1 relies on a combination of purpose provided background ventilation, to supply fresh air, and intermittently operating local extract fans to remove used air (Figure 2).[20] Background ventilation is typically supplied via trickle ventilators (trickle vents) which either may be wall mounted and/or incorporated into the frame of windows and doors (1). Trickle vents provide a small opening to allow for the ingress of drier 'fresh' air and are sized to provide the minimum winter fresh air rate (Figure 3). This removes the need to open windows for the purpose of background ventilation during the heating season, thus reducing unnecessary heat losses. Trickle vents are manually adjustable into open and closed positions, so as to comply with the requirement that all purpose provided ventilation must be '*infinitely controllable'* for the life of the building (Edwards, 2005). It is assumed that, during summer, cross ventilation may be provided by opening the windows (2). Windows are not part of the wintertime background ventilation strategy except where trickle vents are mounted in their frames.

[20] Numbers in brackets refer to label on the diagrams presented in this section.

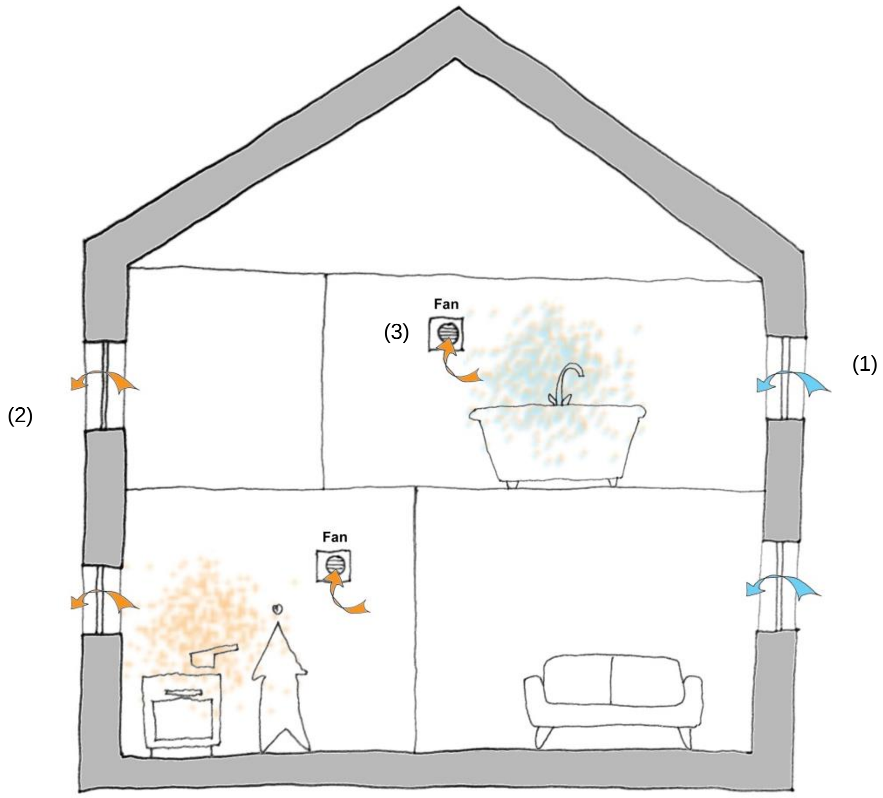

Figure 2: Background ventilators and intermittent extract fans (system 1)[21]

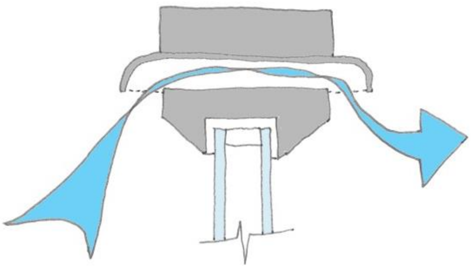

Figure 3: Trickle ventilator installed in window frame[22]

Additional ventilation is required to extract pollutants at source. As pollutants are most frequently generated from household activities in the kitchen and bathrooms, these *'wet'* areas are fitted with wall or ceiling mounted extractor fans (3). Extract fans are electrically powered mechanical devices, which use rotating components to create air movement and flow in a space. Fans can be manually controlled by a switch, or incorporated into lighting controls.

[21] Position of arrows indicative. Air moves through trickle vents, which may be located in the wall or part of the window frame.
[22] Trickle vents may include covers or closers, according to individual designs.

Additionally, humidistat, passive infra-red (PIR) and other sensors can be used to automate the system.

System 2: Passive stack ventilation

Passive stack ventilation (PSV) relies on natural temperature or wind driving forces to extract used air from wet areas, and draw fresh air in via background (trickle) ventilators in the habitable rooms (Figure 4).

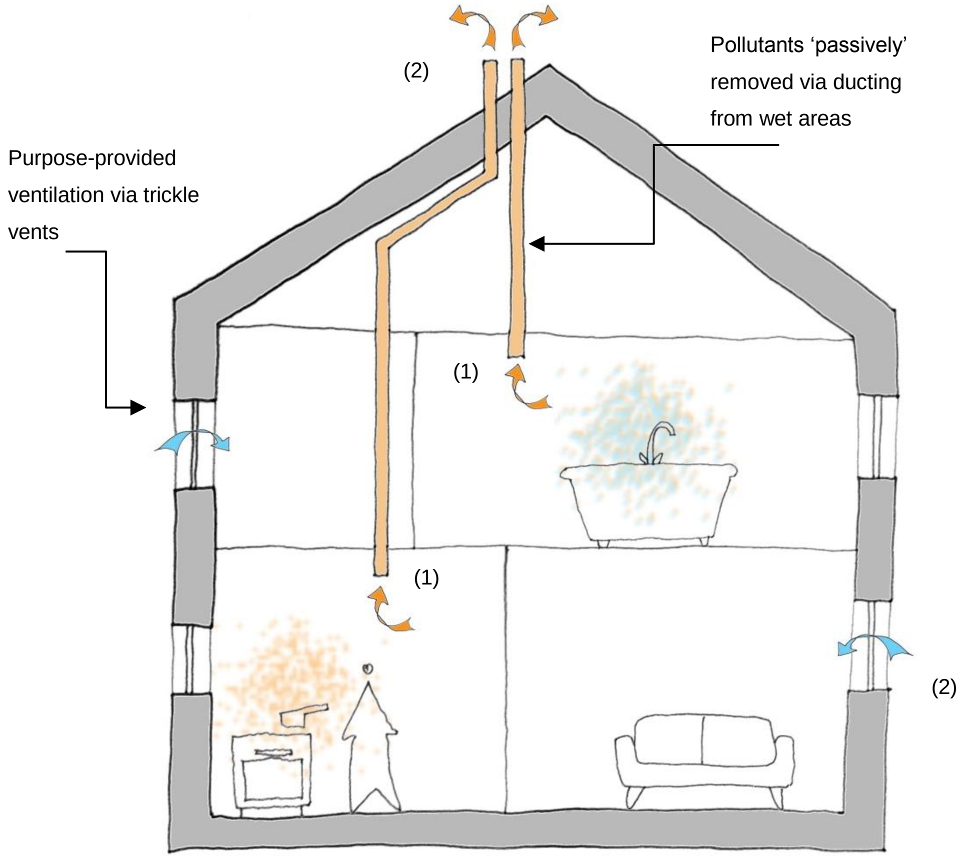

Figure 4: Passive stack ventilation (system 2)

PSV is a type of natural ventilation, hence the term *'passive'*. It does not require any energy to operate; instead, used air is exhausted through ceiling ducts in wet areas (1) and fresh air is drawn into the habitable spaces, via a combination of the stack effect and wind induced pressure differences acting on the exterior facades (2) (Edwards, 2005). Opening windows are not part of the wintertime background ventilation strategy.

The stack effect exploits the difference in density between warm air and cooler air to provide 'fresh' outdoor air to the dwelling (Figure 5). A vertical pressure gradient is created due to this imbalance, which draws the warmer air upwards and out through the provided ducts (1). The wind pressure effect creates a positive pressure zone on the external windward façade (2) and negative pressures on the roof and leeward surfaces (3), which aids the flow of air through the stack (ridge height) as well as in through the trickle vents (CIBSE, 2007).

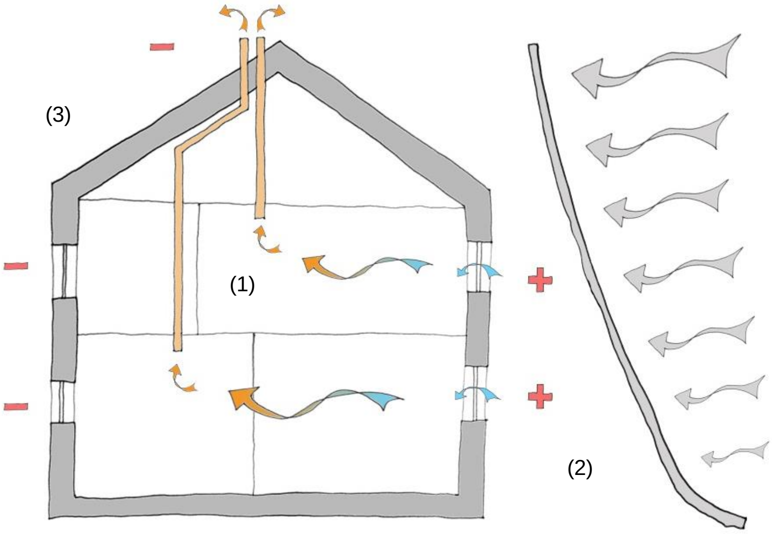

Figure 5: Wind driven flows in a dwelling[23]

A limitation of this technology is that it relies on a steady supply of wind blowing in the right direction as well as a difference between internal and external air temperatures. Therefore, the exact air change rate is hard to predict. Erring on the side of caution may lead to unnecessary ventilation and associated heat losses.

PSV systems are very sensitive to installation (Stephen et al., 1994). Sharp bends in ductwork will cause increased resistance and can reduce airflow. Ideally, a duct should run vertically through the house although a single bend, of no more than 45°, is permitted. Consequently, PSV needs to be considered early in the design process, so that ductwork can be designed to fit in with the building structure and any other mechanical and electrical services.

The energy efficiency of PSV can be improved by incorporating humidity sensors into the duct inlet grilles, to increase the airflow at times when moisture is being generated (typically when RH>65%). This allows the basic ventilation rate to be designed to meet minimum airflow requirements, thus avoiding over-ventilation and the associated heat losses (EST, 2006). Humidity sensors may respond mechanically to humidity changes by incorporating a material such as nylon, which expands and contracts according to humidity (Edwards, 2005). In addition, fan-assisted systems can be used to increase airflows at times of increased demand, albeit at some energy cost.

System 3: Mechanical extract ventilation

Mechanical extract ventilation (MEV) is a continuously operating ventilation system that extracts used air from wet areas and provides fresh air to habitable rooms via background ventilators

[23] Adapted from Russell et al. (2007).

(Figure 6). Extract vents (1) are ducted to a central fan unit, and may be located in any insulated part of the dwelling (2) (Figure 7).[24] The pressure difference between the internal and external space allows fresh air to be drawn in through trickle vents (3), to replace the stale air that is being pulled out through the vents (CIBSE, 2007).

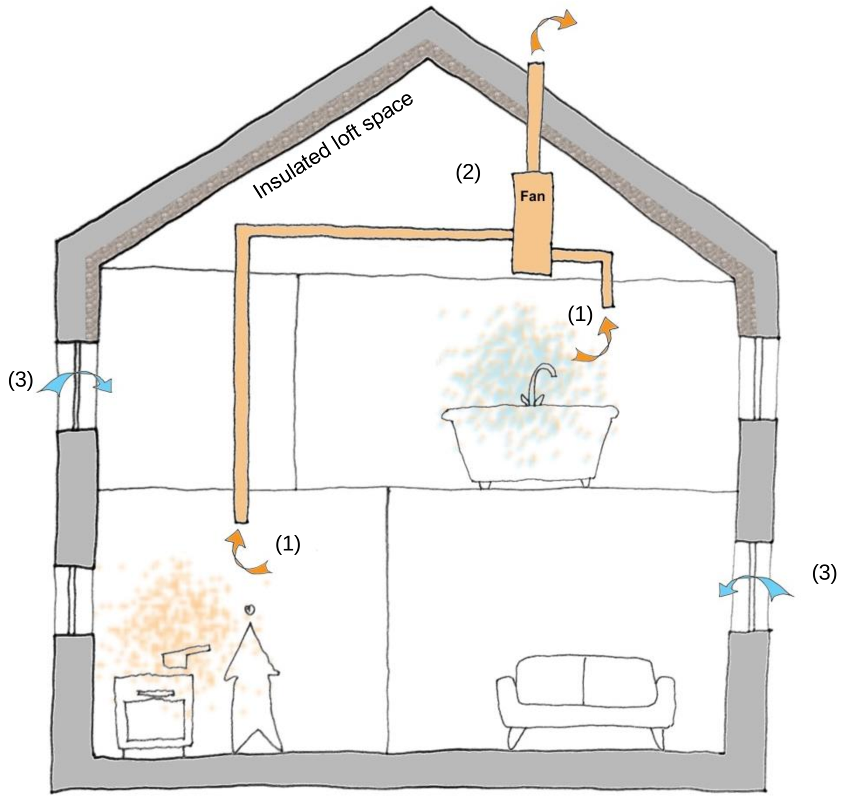

Figure 6: Mechanical extract ventilation (system 3)

Typically, MEV is a *'dual speed'* system so that a continuous minimum ventilation rate is provided at all times, without the need to open windows for background ventilation. A faster speed or *'boost'* setting removes a higher concentrations of pollutants as required. The booster may be connected to a sensor, responding to humidity or occupancy (cia passive infra-red (PIR) sensor), or manually operated, via a switch. The booster is usually set on a timer, so that the ventilation rate is reduced back to the lower setting after a fixed amount of time, e.g. 15 minutes. The length of ducting and number of bends in the ductwork should be minimised as these will cause pressure drops and reduce the efficiency of the system (HM Government, 2010d).

[24] The central fan unit should be located within the insulated envelope of the building to prevent condensation in the ducts and to achieve maximum efficiency by capturing the fan energy as heat inside the insulation.

Figure 7: Installed MEV central unit[25]

System 4: Mechanical ventilation with heat recovery

Mechanical ventilation with heat recovery (MVHR) is a continuous supply and extract system which incorporates a heat exchanger (HE) in the central fan unit, to recover heat from outgoing warm air, which it then uses to preheat incoming cool air (1) (Figure 8).

[25] Image: author's own.

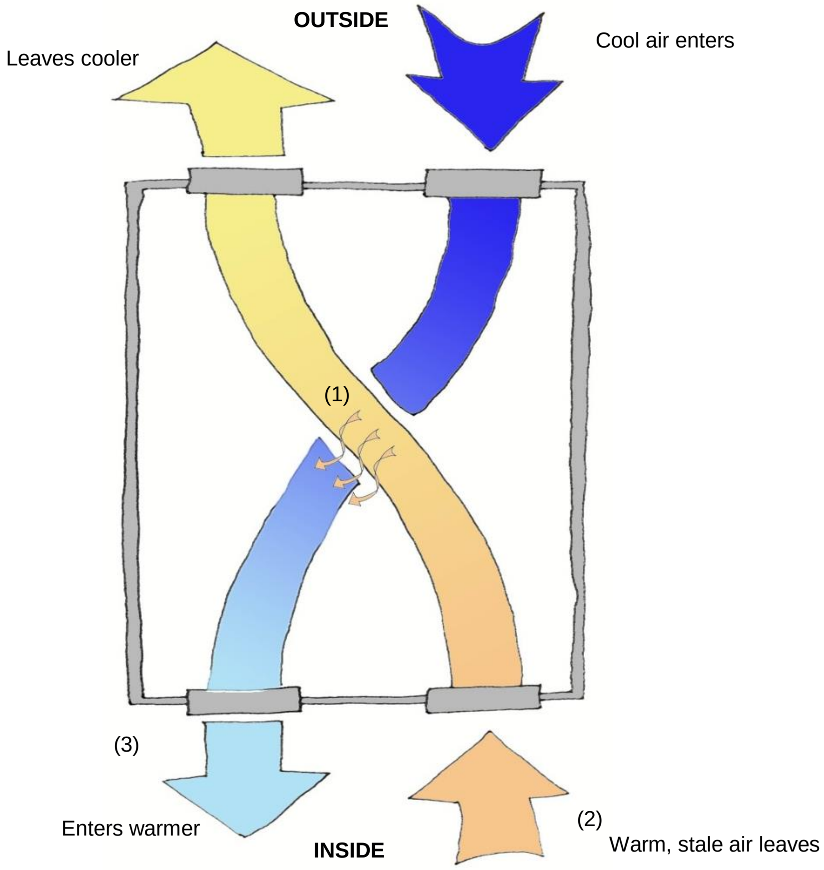

Figure 8: Diagram illustrating heat transfer mechanism

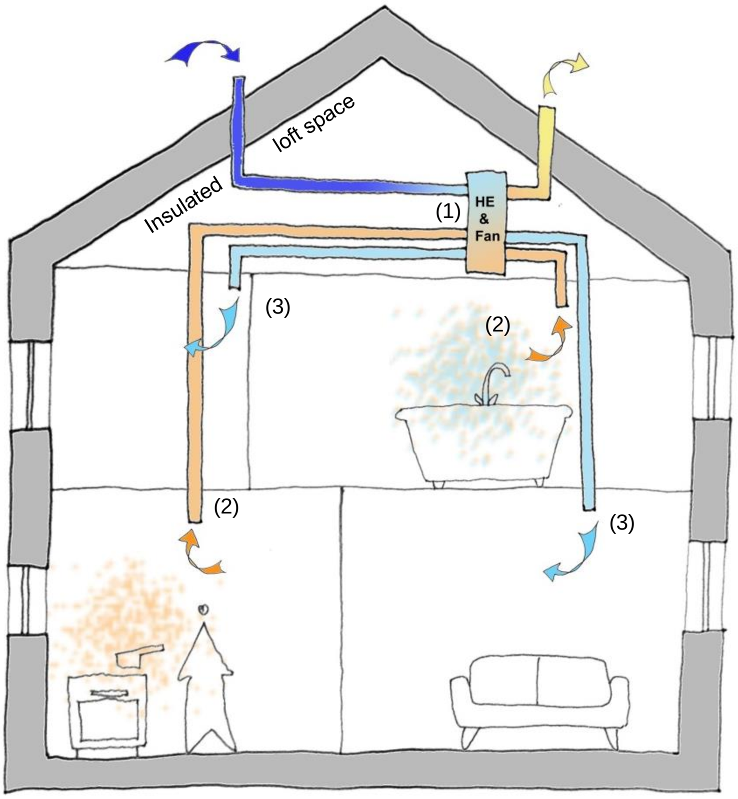

Figure 9: Mechanical ventilation with heat recovery diagram (system 4)

Warm, used air is extracted from wet areas (2) and preheated fresh air is supplied to habitable rooms via a series of ducts (3). The system can be *'dual speed'*, with sensor or occupant controlled boost settings, as outlined in previous descriptions of systems 1 and 3. MVHR is sometimes referred to as '*balanced*' because the fans provide the same volume of supply and extract air, although to improve the efficiency and prevent interstitial condensation the extract flow can be set 5-10% higher than the supply flow, so that the house is slightly under-pressured (EST, 2006).

A summer bypass mode can be included in the central unit so that when the external air temperature is greater than the desired internal temperature, the incoming fresh air is not pre-heated. However, there is currently no reference to summer bypass in ADF, nor in the accompanying Compliance Guide, which may lead to an even greater risk of overheating in LEH (HM Government, 2010a, HM Government, 2010d).

MVHR has the potential to be very energy efficient because part of the dwelling's heat load can be met using the recovered heat, thus reducing the need for additional space heating. However, this will only be the case if the dwelling is sufficiently airtight for virtually all incoming and outgoing air to pass through the heat exchanger. This is because the energy benefits of MVHR are only recognised when the heat recovered is greater than the energy used to run the fan continuously. A field trial conducted by Maier et al. (2009) found that homes with MVHR use 10-30% less energy for heating than naturally ventilated dwellings. An empirical study found no significant difference in energy consumption between MVHR and MEV (Lowe and Johnston, 1997); however, a theoretical investigation calculated that the lowest potential energy use is possible with MVHR, as long as permeability remains below 3 ach@50Pa (Lowe, 2000). This figure does not take into account the additional ventilation provided by window opening. As the author acknowledges (p.9), this is a limitation of the calculation; depending on frequency and duration of window opening, MVHR may not be the most energy efficient strategy after all.

In addition to the potential energy benefits, MVHR is the only approved system which provides a ducted air supply, instead of background vents. This has the advantage of allowing external air to pass through a filter, which can remove sources of PM. As with system 3 (MEV), the length of ducting and number of bends in the ductwork should be minimised as these will cause pressure drops and reduce the efficiency of the system (HM Government, 2010d).

Maintenance requirements

Each of the four systems requires some maintenance to ensure that they are operating effectively. Systems 1 and 2 are relatively simple in terms of operation and require only minimal maintenance, such as the occasional cleaning of extract ducts and fan covers. The continuous systems (3 and 4) require additional maintenance as the fan units can contain a filter to prevent damage to the fan (system 3) and may also filter incoming air (system 4). These need to be cleaned or replaced regularly (3-6 months). Heat exchangers should be checked for blockages (HM Government, 2010d).

Additional requirements

An additional requirement of all the approved systems is the provision of a gap of at least 7600 mm^2 under each internal door, to permit the free movement of air between the spaces (HM Government, 2010a).[26] For all four systems, purge ventilation is required and is normally provided by openable windows.[27] Windows must open by at least 15 degrees to contribute to purge ventilation.[28]

2.2. The co-evolution of housing design and domestic ventilation in the UK

The strategies presented in the previous section, for designing homes with WHV, are very different from those adopted in traditional, naturally ventilated homes, which were being constructed as recently as 50 years ago. This section discusses the dynamic development between building fabric and ventilation in housing during four historical periods. The aim is to illustrate that ventilation strategies and systems develop not only as a result of technological innovation, but that they coevolve alongside changes in the way society is organised. The following four periods are analysed to demonstrate how housing, ventilation and the wider social infrastructure have co-evolved into today's system, or 'arrangement':

- C12th - 1700: Pre-industrialisation and communal living
- 1700 - 1900: From bad air to good air
- 1900-1984: The modern home
- 1984 - 2014: The building regulations; WHV becomes mainstream

2.2.1. Pre-industrialisation and communal living (C12th - 1700)

The Medieval hall

People have always relied on a combination of '*technical resources and social organisation'* to temper their environment (Banham, 1984 p.18). In the Middle Ages, before the rise of the nuclear family, society was structured into large households based around feudalism. During this time, in the region which is now Great Britain, the size of a typical household peaked to include dozens of members, from bailiffs to stewards and servants to gardeners (Aslet, 2008, p.25). Unlike the modern home, where the public and private realms are separated via a series of interconnecting spaces and storeys, the Norman household was centred around a single enclosed space, or 'hall', which would be transformed from meeting space, to dining room, to

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[26] This is equivalent to a gap of 10mm under a standard width door of 760 mm.

[27] Alternatively, a manually operated fan providing 4 ACH may be used instead (e.g. in an 'internal' room with no external walls or on very noisy roads).

[28] For hinged or pivot windows with an opening of at least 30º, or for parallel sliding windows, the area (height x width) of the opening part should be at least 1/20th of the room's floor area. For hinged or pivot windows that open between 15º and 30º, the height x width of the opening part should be no less than 1/10th of the room's floor area (HM Government, 2010a, p.47).

dormitory, over the course of the day (Figure 10). Animals and livestock also lived in the hall alongside their keepers and there were no separate bedrooms (Worsley, 2012).

Figure 10: An early 12th Century home: The great hall at Oakham [29]

Heating was provided by burning wood on a large central hearth, from where smoke rose up and out via louvres in the steeply pitched roof (Aslet, 2008, p.26). This process was aided by draughts entering through wooden shutters (as fire requires oxygen to burn), as early domestic windows contained cloth protected by shutters instead of glass; therefore, ventilation was a passive and hard to control process akin to what we call 'infiltration' today. The sight and smell of smoke would have filled the interior of the hall at times, stinging eyes and leaving a visible sooty stain on the walls and ceiling, resulting in an environment that would now be considered unhealthy.[30]

The purpose of this arrangement was to keep everyone together, safely and warmly. Providing warmth and shelter from rain were the main environmental concerns which were to be fulfilled in the medieval home. The arrangement of a single space around a central fire was effective both environmentally and socially, in the feudal society. The importance of this social and spatial organisation is emphasised by the fact that '*early censuses didn't count people or houses: they counted "hearths", as the cooking fire was the central point of a home'* (Worsley, 2011, p.241).

Early family homes

This notion of home as a complete community, or household, was eventually replaced by ideas of comfort and privacy, which by the Victorian era had become '*essential qualities of home'* (Aslet, 2008, p.28). In the late 16th Century, brick became the building material of choice for the construction of homes. The use of brick, rather than stone, enabled the construction of houses with thinner walls and a variety of separated internal spaces. Separate spaces required multiple fireplaces to stay warm, and so chimneys became a common feature in houses. At last, people

[29] Left image from Wall Panelling (2010) and right image from Rutland County Council (2011).
[30] Around 3 billion people around the world still rely on open fires and simple stoves to heat their homes and cook food. More than 4 million people are thought to die prematurely from products of such combustion (WHO, 2014).

were able to warm their homes without suffering the ill effects of soot and smoke (Figure 11). Chimney pots and a large, ornate chimney stack were a symbol of wealth, as they represented a warm and comfortable home (Aslet, 2008). Some became so ornate that they have been described as '*houses in miniature'* (Goodall, 2011), incorporating '*fleurs-de-lys, fancy bricklaying, extruding turrets and even little brick masks' (Aslet, 2011)*.

Figure 11: Chimney stack at Hampton Court Palace[31]

Another technical innovation introduced at this time was glass, which could now be used to fill small windows, reducing (although by no means preventing) draughts. The Elizabethan aristocracy developed a fondness for sparkly glass and the idea of home as a place of delight and pleasure, as opposed to simply function, was born: '*For the first time the inhabitants of English houses had a reason for staying inside, other than shelter and warmth'* (Aslet, 2008, p.57). It was around this time that the architect became a professional individual; previously, buildings would have been designed and constructed by skilled craftsmen (Rickaby, 1979). The level of knowledge required to do this was now still within the limits of a single mind; for example, heating was invariably provided by burning fires and the through draught this created was sufficient to remove the visible pollutant of soot; complex engineering solutions were not required yet.[32]

2.2.2. From bad air to good air (1800 - 1900)

The 19th Century saw rapid changes in society and many technological advances. As the complexity of buildings increased, a single person was no longer able to oversee every aspect of a building's design and construction. New professions such as engineering were formed during this era (Rickaby, 1979).

[31] Image reproduced from Aslet (2011).
[32] Cooking smells were not the concern they are today, as kitchens were still generally located in semi-separate buildings rather than the main house (Worsley, 2012, p.250).

The industrialisation of the economy was accompanied by rapid urbanisation as people moved to cities for work. People living in denser environments were more susceptible to health epidemics, such as cholera. Furthermore, the close proximity of factories and railways to people's homes increased air pollution and the relationship between increased mortality rates and poorly ventilated workplaces was observed (Banham, 1984). For the first time the connection between ventilation and health became a serious concern. Perhaps unsurprisingly, two key texts about ventilation of buildings at this time were written by medical doctors: "Notes on the ventilation and warming of houses, churches, schools and other buildings" (Jacob, 1894), and "Health and Comfort in House-building" (Drysdale and Hayward, 1872). At that time doctors generally visited patients at home so were in a good position to observe the conditions in which people lived, often finding them shockingly unsanitary.[33]

In the 19th Century, smell and feeling draughts were the main ways in which people observed and monitored ventilation, as devices for accurately measuring RH and CO_2 were not yet widely available (Camuffo et al., 2014). The main challenge of ventilation in this era was to eliminate smells without causing draughts (Banham, 1984). The popular account of how the physician John Snow dispelled the myth around 'miasma',[34] or bad air, after pinpointing the 1854 outbreak of cholera to a water pump in London and paving the way for a theory of waterborne disease spread via bacteria, highlights the great virtue that late Victorian society placed on fresh air (McLeod, 2000). Before then, air, especially night air, was feared as it was believed to cause disease by spreading poisonous vapours. Doctors warned that '*disease would enter middle-class homes by wafting on the breeze from the slums'* and it was common practice to keep windows closed at night (Baldwin, 2003). Only when it was discovered that mosquitos were the cause of diseases such as malaria[35] did the fear of bad night air begin to dispel.

Large amounts of housing were constructed during this period to meet the demand for urban and suburban homes. A substantial proportion of our existing housing stock dates from this era, evident in the rows upon rows of brick terraces found in British towns and cities. This type of house was built by early speculative developers and follows a remarkably uniform arrangement, with a fireplace in each room, large sash windows, suspended timber floors and airbricks. This configuration provides the ideal conditions for maintaining a steady flow of air through the house.

The Victorian era was also a time when, for the first time, material wealth was sufficient for people to *'stuff their houses full of objects'* as they sought to create a space which expressed their personalities and tastes (Cohen, 2006). Consequently, the image of the cluttered home

[33] This is an example of how doctors used to provide much more holistic healthcare by visiting people at home and seeking the cause of a condition, compared to the current arrangement where the focus is on diagnosing and treating the disease.
[34] Miasmic theory was pervasive until the late 19th Century and stated that disease was spread through the inhalation of 'bad' or 'corrupted' air (Halliday, 2001).
[35] The word malaria is a translation of 'bad air' in Italian.

and a fascination for home decoration boomed during this time. Even in death, one's possessions were remembered (Boyd (1861) in Cohen (2006)):[36]

> *'Memories of carpets and curtains, reported one country parson, were "among the things which come up in the strange, confused remembrance of the dying man in the last days of his life"'*

2.2.3. The modern home (1900-1984)

Connected infrastructures

The early 20th Century was characterised by great changes in infrastructure, which saw homes connected to a national electricity and gas network, huge improvements in domestic plumbing and the decline of coal fires as the main source of heating. Although the technology for electric lighting was invented in the late 19th Century, this innovation could not be deployed into homes until a system was developed to supply electricity to dwellings, which only happened several decades later (Banham, 1984). Once a central electric grid was in place, existing and new homes could be connected and electric lighting rapidly replaced gas and oil lamps. Once homes were connected to the grid they were able to make use of electrical appliances, such as the iron. By the mid-1950s, 50% of households had installed plug sockets as well as lighting.[37]

Similarly, the invention of a stove which could heat a room by convection, as opposed to the radiation emitted from an open source of heat, is attributed to Benjamin Franklin in 1742 (Banham, 1984). However, it was not until the late 20th Century that central heating would become widespread in the UK. This only became possible with the availability of gas in homes; now, hot water could be heated and circulated around the house efficiently (Palmer and Cooper, 2013).[38] Another possible reason for the slow uptake of centralised heating relates to the social structure of households. Maintaining a coal fire was dirty laborious work. With the decline of domestic labour in post-war Britain there was no longer the time, nor means, to stoke an open fire. Long (1993) argues that it was this adjustment in household composition that prompted many people to, despite their initial scepticism, adopt gas heating, first in the form of gas fires and then later with the introduction of gas central heating using hot water, a system that is dominant today (Palmer and Cooper, 2013).[39] The move to using electricity and natural gas in homes also meant that energy use became 'invisible' in homes.

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[36] The original text was not found in the referenced book.

[37] In 1920 only 6% of British homes were connected to the electricity grid but by 1939 more than 2/3 of homes had had access to electricity from the grid (Hornsby, 2010).

[38] UK dwellings were first connected to privately operated gas networks supplying 'town gas' in the 1840s, which were replaced by the National Transmission System in 1969 following the discovery of natural gas in the North Sea (Dodds and McDowall, 2013).

[39] By 2009, 89% of UK households had central heating, compared to only 26% in 1970 (Palmer and Cooper, 2013, p.46). Over 90% of centrally heated homes use gas as the main fuel (i.e. in 80% of all homes).

Moisture moves in

With the separation of combustion sources from the site of the delivery, the burden on ventilation to remove smoke was reduced.[40] However, simultaneous changes in the provision of sanitation and hygiene practices meant that dispelling excess moisture became a more serious challenge. Indoor bathrooms were a rarity in the UK before 1900 and en-suites did not become common until the 1980s (Worsley, 2012). In the post-war period there was a drive to modernise housing. The Housing Act of 1949 provided funds for improvements to homes, which included the installation of indoor WCs and baths and connecting to the sewerage system. The Housing Act of 1969 expanded the scheme of grants, in an attempt to improve take-up (Scanlon, 2010).

Once a supply of hot water was available on tap and people became accustomed to frequent washing and bathing, the amount of moisture produced in a home would probably have risen rapidly, bringing with it a new set of concerns around condensation, mould and damp; by the 1930s most ‘middle class’ homes had piped access to hot and cold water and by the 1950s this service had spread to all homes (Hand et al., 2005). Not only were households producing more moisture, but methods of construction were also changing. The new homes which were built over this period were the first to be designed with modern services in mind, so it was no longer necessary to provide fireplaces or chimneys. Developments in cement and mortar, and the use of metal-framed windows, meant that the building envelope was no longer permeable or ‘breathable’. Owing to these changes ventilation rates would have reduced and moisture concentrations risen.

Although single room extract vans were available from the mid-1930s (Vent-Axia, 1970s), it was only once bathrooms and kitchens had moved indoors, and homes had become more airtight, that they proved to be indispensable. The widespread use of mechanical ventilation in domestic settings is relatively recent. While the separation of spaces by function reached its peak in the Victorian home, the introduction of the extractor fan has enabled more fluid living arrangements demonstrated in the recent popularity of open plan kitchen, living and dining spaces (Worsley, 2011, p.256). Unfortunately, many homes remain poorly ventilated, and, although incidence of moisture related problems is gradually falling, as recently as in 2001 10% of dwellings had a damp problem (CLG, 2011).[41]

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[40] For example, electricity being created in power stations and boiler fumes contained in ductwork.

[41] The “English Housing Survey, Housing Stock Report 2009” found that 8% of dwellings have a problem with damp, rising to over 20% in poor and ethnic minority households (CLG, 2011). The prevalence of damp appears to be falling slightly, from 10% in 2001 to 7% in 2010; however, condensation and mould are still a problem in some 700,000 homes (3.5%) (CLG, 2012b). It is possible that this is partly due to lower occupancy densities, a trend which may reverse if the current housing shortage continues.

Low energy pioneers

The earliest concerns about the supply and cost of energy took place in response to the 1970s oil crises. An environmentalism movement was born, based on a realisation of the limitations of the world's natural resources (Catton and Dunlap, 1978). For the first time, ventilation had to meet the three challenges which were discussed above: providing fresh air, maintaining thermal comfort, and conserving energy.

One of the earliest known examples of a very low energy house in a cold climate is the Saskatchewen Conservation House in Canada. Completed in 1977, the house is airtight, extremely well insulated and contains an air-to-air heat exchanger with mechanical ventilation, or MVHR (Besant et al., 1979). This was a pioneering project, constructed nearly 15 years before the first PassivHaus was built in 1991 (Schiano-Phan et al., 2008). The first superinsulated houses with MVHR in the UK were built in the 1985 at Two Mile Ash, Milton Keynes (Anon., 1986, p.28). Unfortunately, this method of building was not to become part of mainstream construction in the UK for almost 40 years.

2.2.4. The building regulations: WHV becomes mainstream (1984 – 2014)

Increasing regulation of housing construction

Over the last three decades the construction of housing has become increasingly regulated. The first national building regulations, published in 1965, included sections *on 'open space, ventilation and height of rooms'*, '*Chimneys, flue pipes, hearths and fireplace recesses'* and *'thermal insulation'*.[42] [43] However, there was no reference to energy consumption (Ley, 2000). Following the Building Act 1984, the regulations were rewritten into a similar format as they are at present, from when they continually evolved into today's documents (Jenkin, 1985). Now, rather than detailing individual regulations, the approved documents set out the requirements and then suggest methods for compliance, whilst allowing scope for alternative methods of compliance to be proposed by designers. In 1985 ADL, "Conservation of Fuel and Power", was added.[44] Since then, revisions have become gradually more frequent as regulation is tightened and the complexity of buildings increases (see Table 8, which outlines when successive versions of the approved documents were published).

For example, ADL was initially one document which, following the 2002 revision was split into two documents (ADL1, ADL2), which addressed domestic and non-domestic buildings

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[42] Previously, regulations were independently established in individual municipalities so that by the 18th Century there was a form of Building Control in many British cities (Manco, 2009).
[43] The first UK legislation to address ventilation in housing was the Public Health Act 1845 (Gann et al., 1998).
[44] That is, as a series of statutory instruments with an accompanying set of approved documents outlining best practice for compliance. Previous versions of the regulations were more prescriptive.

respectively. In 2006, each of these was split again, to distinguish between work to new (ADL1A) and existing (ADL1B) buildings. Since 2010, ADL has been revised almost annually. ADF was first revised in 1995, and then in 2006, 2010, 2011 and 2013. The "*Domestic Ventilation Compliance Guide*" (HM Government, 2010d) replaced Appendices D and E of ADF in 2006 (HM Government, 2006).

Table 8: Building regulations revisions - key dates[45]

1965	The Building Regulations 1965 - first national building regulations			
1984	The Building Act 1984			
1985	Approved Documents published - Part L introduced and new format presents regulations as a set of requirements and suggestions for compliance			
Year	ADF	ADL	Code for Sustainable Homes (CSH)	Research case studies' completion dates[46]
1995	ADF 1995	ADL		
2000	Amendments to 1995 version		EcoHomes	
2001				
2002		ADL1, ADL2		
2003				
2004				
2005		Interim editions of ADL1A, L1B, L2A, L2B		Case A (MEV)
2006	ADF 2006	ADL1A, L1B, L2A, L2B	Code for Sustainable Homes (CSH)	
2007				
2008				Case C (PSV)
2009				
2010	ADF 2010, Domestic Ventilation Compliance Guide	ADL1A, ADL1B, ADL2A, ADL2B		
2011	Amendments to compliance guide	Amendments to ADL1B		Case B (MVHR)
2012		Amendments to ADL1B and ADL2B		
2013	Amendments to 2010 version	ADL1A, ADL2A Amendments to		

45 Although beyond the scope of this thesis, it can be assumed that other parts of the building regulations, such as those relating to accessibility (ADM), fire (ADB) and contaminated land (ADC) have followed comparable trajectories. These may also have an indirect impact on ventilation, e.g. fire doors.

46 The case studies examined in this thesis were completed in 2005, 2008 and 2011 and were therefore built to different versions of ADL and ADF (refer to Chapter 5: for further information).

	ADL1B and ADL2B
2015	CSH withdrawn from planning requirements

This added complexity (as evidenced by the size of the documents) adds challenges for designers and building control officers, few of whom comprehensively understand the regulations, and who are now faced with ever more things to consider. It is no longer possible for one person to oversee all aspects of building design and construction. Instead, there are now often large design teams, which, even on a modestly sized housing development, will comprise, structural engineers, mechanical and electrical (M&E) engineers, environmental consultants, SAP assessors, planning consultants, building control bodies, contractors and many other subcontractors and tradespeople, all working alongside the architects.[47]

As more people with different skills become involved in the construction of homes the need for clear communication between all the parties becomes increasingly critical and the level of bureaucracy increases. Designing and delivering a well performing LEH within the constraints of today's construction industry is not a simple task.

Evolution of ADF and ADL

A key change in ADL, since its introduction in 1985, relates to an incremental reduction in the CO_2 emissions associated with the building's energy use, so that in theory a dwelling designed according to ADL1A 2013 will contribute 6% less CO_2 than one designed to comply with the 2010 version, and a dwelling designed according to ADL1A 2010 will theoretically contribute 25% less CO_2 than one designed to comply with the 2006 version (HM Government, 2010c). ADL1 2006 was the first to mandate that design CO_2 emissions are calculated using SAP and with reference to a *'notional dwelling'* (ODPM, 2006). Previous versions permitted the use of the '*Elemental Method'* and the *'Target U-value Method'* to demonstrate compliance. These granted compliance based on a criteria such as maximum U-values, acceptable heating types and maximum permitted window and door areas (HM Government, 2002). As the elemental method was replaced by the SAP methodology, an airtight building envelope has become increasingly desirable in terms of ADL compliance. This is because permeability scores contribute towards SAP value but were not considered by the elemental method. The link between ADL compliance and SAP rating mean that achieving a good SAP rating has become very important in building programmes and it is possible that SAP may inadvertently incentivise certain systems or solutions over others.

[47] In 2013 45% of new UK housing was built by 10 house building companies (by completion). (HBF, 2015), while the self-build and custom built market accounts for only 7-10% of completions (Wilson, 2015).

The key difference between the 2010 and 2006 versions of ADF relates to the commissioning and testing of fixed mechanical systems and controls, something which was not required in previous versions but is now compulsory (HM Government, 2006). A further requirement that is new to the 2010 revision is the need to provide ‘sufficient’ information about operation of the ventilation system for building owners (HM Government, 2010a). At this point, domestic ventilation was classed as ‘notifiable work’ which must be installed by a registered electrical installer.[48] A new BPEC (British Plumbing Employers Council) qualification was also launched to provide the mechanical competencies and skills required to meet the new requirements, and to encourage the formation of a new vocation, the ‘Domestic Ventilation Installer’. Whereas previously plumbers and electricians were responsible for the ventilation installation, a new trade has developed around the new regulation. This has implications for ADL compliance too. If the ventilation is installed by someone who doesn't have this qualification an 'in-use factor' is applied in SAP, to account for likely poor installation and commissioning practices.[49]

ADF was previously updated in 2000. This version of the regulations predates the introduction of whole house ventilation systems and refers only to ventilation rates for *‘rapid ventilation’* and background ventilation provided through openings such as trickle vents and airbricks (HM Government, 2000). There is also no mention of handover procedures and commissioning is only briefly mentioned. The idea of four approved systems was introduced in ADF 2006 (HM Government, 2006).

A choice of four systems

It is interesting that there are currently four different ventilation systems ‘approved’ by the building regulation and that the advancement of technology has not superseded the more simple strategies. Instead, natural and mechanical ventilation strategies have been developed simultaneously.[50] However, their uptake within new housing is uneven; the prevalence of MV has increased greatly over the last decade.

As discussed previously, MVHR is only viable (in primary energy or CO_2 terms) when a building is sufficiently airtight for more heat energy to be recovered than electrical energy is expended by the fan.[51] In the past, British housing simply wasn’t airtight enough for this to be the case. It appears that only when the supporting trades and industries were able to deliver a very airtight dwelling that MVHR could become a useful technology; in this case it may not have been

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[48] ‘Notifiable work’ refers to electrical work which must either be carried out by a registered installer or be checked by building control or a registered third party (DCLG, 2015a).

[49] The in-use factors relate to the efficiency of the fan (SPF), as shown in Appendix E: Supporting Material for Chapter 2, Table 37.

[50] Though the earliest MV systems were found in non-domestic buildings and their transition to housing is more recent.

[51] It is worth noting that with current gas central heating systems low embodied carbon gas energy is being replaced by high embodied energy electricity for the fan. If the electricity system is decarbonised in the future this will no longer be the case.

technological innovation that was lacking but rather the skills and competencies of the housing industry that needed to ‘catch up’ with the technology. Furthermore, a number of incremental improvements such as sensors, summer bypass modes and the move to rigid ductwork have helped increase the efficiency, and therefore viability, of this technology.

In the meantime, trickle vents were tested in an attempt by UK housing to meet the three ventilation challenges simultaneously. A demonstration project in South Wales (Abertridwr) found a notable decrease in condensation without incurring ‘*a significant energy penalty’* in a development of 17 homes that had been retrofitted with trickle vents (O'Sullivan and Jones, 1982, p10.19). Trickle vents were part of a natural ventilation strategy which would later be supplemented with intermittent extract fans (System 1, IEV) or vertical air ducts (System 2, PSV). Intermittent extract fans and continuous mechanical extract ventilation were probably first deployed in non-domestic settings and were introduced into housing during the 1990s (Bell and Lowe, 2000). With homes getting more airtight and electrical fans more widespread the jump to heat recovery may seem inevitable; however, uptake in the UK market has been slow compared to other parts of Europe, perhaps because the building regulations do not mandate it.

Since 2011, half of new homes built in the UK include continuous mechanical ventilation systems, compared to only 5% in the period between 2001 and 2010 (REVHA, 2012). A report by CLG (2012a) states that between April 2007 and June 2012, 25,674 (3.9%) dwellings were constructed to CSH Level 4 rating, the majority of which probably utilise MVHR. [52] [53] This amounts to less than 0.1% of the current housing stock and approximately half new homes built over this period (CLG, 2010, Green, 2011).[54]

The situation in the UK is not representative of that across the rest of Europe where ventilation technology uptake has followed a different trajectory. For example, the Swedish building regulations have required MVHR and 3 ACH_{50} since 1982 (Lowe and Johnston, 1997). A study by REVHA[55] investigated the diffusion of different domestic ventilation technologies in several European countries. It found that by 2003 MVHR accounted for around 15% of the market share of ventilation in new homes in the Netherlands. On the other hand, Finland started installing MV systems in 1959 and by 2004 100% market penetration had been reached, with supply and extract systems accounting for 93% of the total share (see also Hänninen et al. (2005)).The report implies that the reason for this variation between countries is to do with historical changes in building codes which prompted a step change in construction practices (REVHA,

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[52] (DCLG, 2012)
[53] This number applies to ‘design-stage’ ratings, compared to a post-design number of 9,802 Level 4 homes. It is assumed that homes designed to meet Level 4 will include MVHR even if ultimately the requirements for compliance were not fully realised and the project was awarded Level 3 instead.
[54] See also Rohracher, (2001b) which states that less than 1% of new flats in Austria are built with MVHR.
[55] The Federation of European Heating, Ventilation and Air Conditioning Associations.

2012). This is probably true to some extent but only tells part of the story; comparing the UK situation to other parts of Europe, hints at how regulations, design standards, building traditions, climate and the capabilities of the construction industry can all play a role in the deployment of technological innovations.

2.3. Conclusion: A complex and evolving system

2.3.1. A complex system

This chapter presented an overview of the historical coevolution of housing, ventilation technologies and social actors. The aim was not to present a comprehensive history of the subject, but to demonstrate how the social and technical aspects of ventilation cannot be separated from one another, and to analyse the context for the current challenges facing ventilation in LEH. During each historical period, multiple technological and social transitions occurred simultaneously, such as changes in heating fuel, ventilation systems, housing construction and layout, as well as evolving environmental and energy concerns. The formation of new professions meant that one person was no longer able to oversee every part of the building process. This introduced the potential for miscommunication and conflicting priorities to affect the design of ventilation systems and to hinder their ultimate performance. Regulation has also been introduced to protect people's health and to save energy, while comfort has always played an important role in the design of new housing. Some of the social and technical aspects of domestic ventilation are illustrated in Figure 12.[56]

[56] This diagram is based on Geels' idea of a socio-technical system, a cluster of interrelated social and technical elements, which will be discussed further in the next chapter (Geels, 2005, p.2). It is not intended to provide a definitive list of all aspects of a socio-technical ventilation system, but to demonstrate the potential extent of such a system's reach.

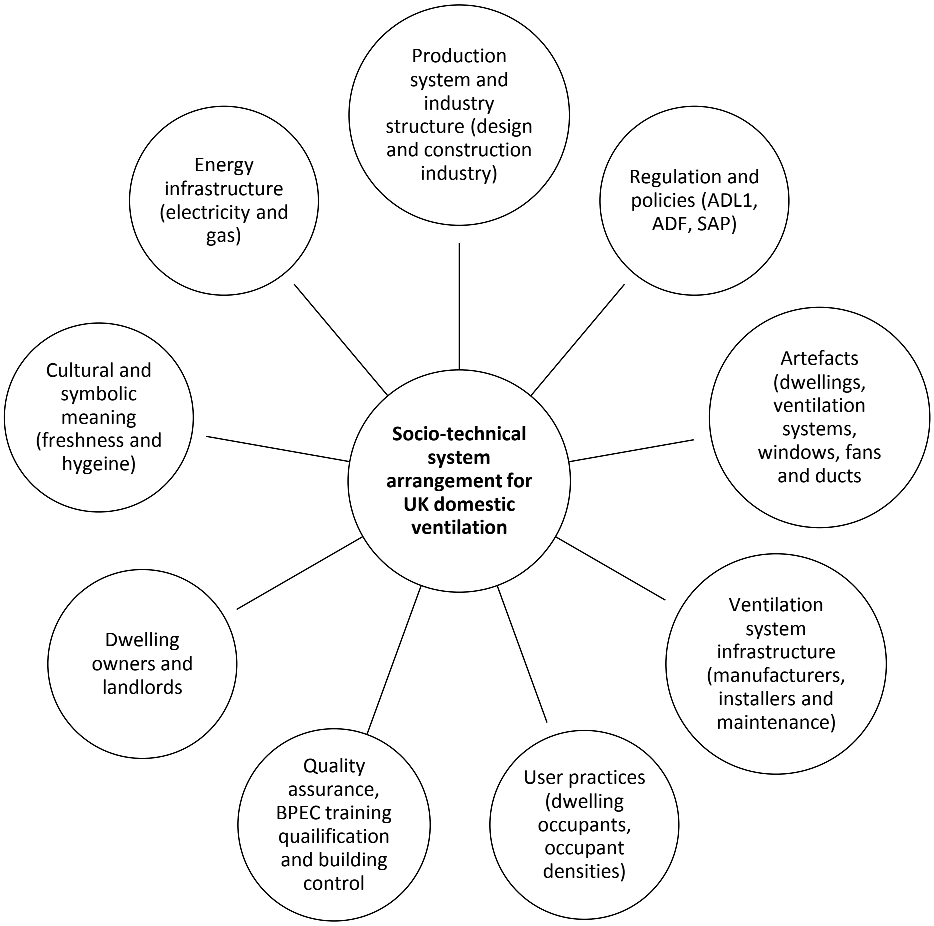

Figure 12: Socio-technical system arrangement for UK domestic ventilation

The current socio-technical system arrangement for UK domestic ventilation is very complex. While ventilation was historically introduced to remove pollutants generated through heating systems (e.g. coal fire smoke), it now has to balance IAQ with tightening energy efficiency requirements. Furthermore, as there are four approved systems for delivering ventilation in new homes people potentially have to understand several different ways of ventilating their home, not just one. Designers and constructors are also faced with at least four different sets of technologies choose from when specifying a system. If they do not understand the implications of their choice it is hard to make the most appropriate decision and to deliver it well. The creation of a successful new home now relies on input from a range of consultants and stakeholders and is not straightforward. It increasingly relies on technologies which were developed for non-domestic applications (e.g. heat exchangers) and were then transferred to housing.

As demonstrated in section 2.2, this complexity is a recent development, as for much of the past homes were naturally ventilated using windows, air bricks or air infiltration. Looking at historical evolution also demonstrates how individual technological innovation itself does not guarantee successful commercialisation, nor lead to changes in the way homes are ventilated; only when the infrastructure exists for it to be adopted by a wider group of users can a technological transition occur. For example, electrical appliances could not be used in homes until there was a system in place to deliver power to housing, and MVHR wasn't an effective ventilation solution until dwellings became more airtight.

The current regulations are based on various theoretical assumptions about how different types of ventilation may work; however, there is limited evidence of actual ventilation rates in occupied homes, as this is challenging and expensive to measure.[57] Furthermore, there is uncertainty about how people interact with ventilation technologies such as windows and trickle vents (see section 3.2.3). As the social and technical are so evidently interconnected, this thesis adopts the position that to fully understand the role of ventilation in maintaining a healthy, comfortable and energy efficient environment, a socio-technical approach must be taken.[58]

2.3.2. Industry is moving towards MVHR

MVHR is a complex technology which is still quite rare in today's housing stock. It is relatively expensive to install and requires technical expertise. For example, in some instances residents have complained of excessive noise from systems which were poorly installed (Macintosh and Steemers, 2005). Nonetheless, as airtightness increases in response to the demands of ADL and SAP, it is predicted by some that MVHR will eventually become the norm in new UK housing (NHBC and ZCH, 2012). These recent development fulfil the prediction voiced in the 2005 book "*Handbook of Domestic ventilation*", where the author reasons that '*it is hard to escape the conclusion that the imposition of a prescriptive airtightness standard for dwellings would push the construction industry towards the use of the centralised mechanical ventilation systems, providing both supply and extract air and almost certainly employing heat recovery from the exhaust'* (Edwards, 2005, p.245).

However it is important to note that this move towards MVHR is based on a theoretical calculation of the energy saving potential of the system, which does not take into account the reality of systems in use. Despite the increased complexity of methods used to inform housing design and assess compliance, the assumptions remain a simplification of what is a very complex system made up of many physical components, policies, regulations and stakeholders. To demonstrate some of this complexity, Figure 13 illustrates the wide range of social groups involved in domestic ventilation installation and use.

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[57] Large scale studies have focused on pressure testing unoccupied homes; for example, a study of 471 homes by the Building Research Establishment (BRE) found the average infiltration rate during pressure testing to be 13.1 ach@50pa (Stephen, 1998).
[58] The term 'socio-technical' will be explained in more detail in the Chapter 3 and Chapter 4.

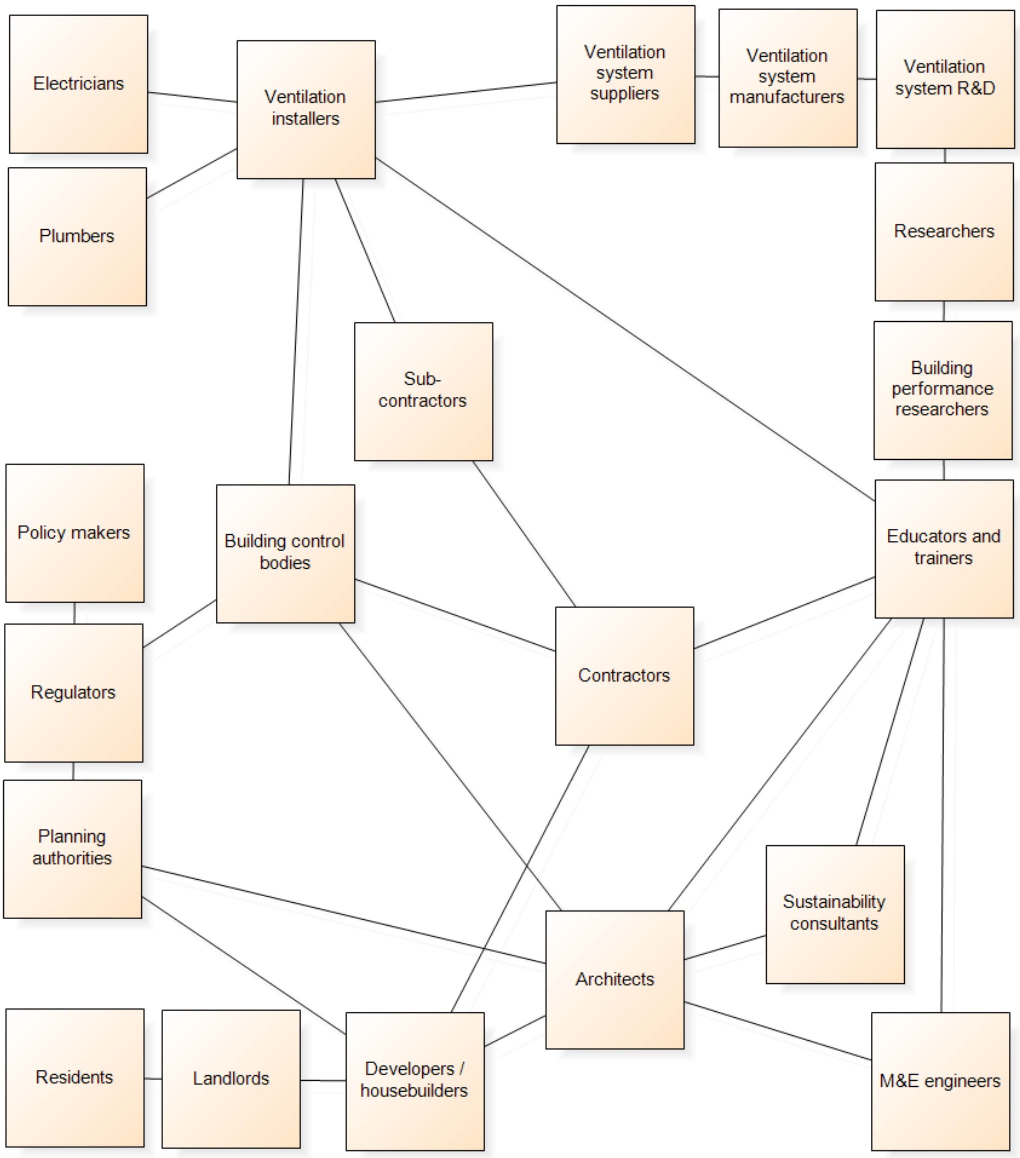

Figure 13: Social groups involved in domestic ventilation installation and use

Given the limited empirical evidence of the impact ventilation systems have on energy use there is a heavy reliance on theoretical modelling, which may oversimplify this complex problem and which depends on many invalidated assumptions. For example, based on the figures in Table 7 (p.27), ACH, and therefore heat energy consumption, would be notably greater at times when windows are open; however, as SAP assumes that windows are closed during winter in MV installations, it is unsurprising that a performance gap is often reported between predicted and actual energy consumption of homes (Janda and Topouzi, 2015).

Another reason for a potential increase in the use of MVHR is that household composition is changing as we see a rise in single person households (Palmer and Cooper, 2013), and continued urbanisation; therefore, the housing industry may evolve in response to this by providing more inner-city apartment buildings and single parent family homes. It is difficult to design a high performance, low energy, and naturally ventilated small apartment that relies solely on NV. It seems that long term, the construction industry may be being pushed towards MVHR.[59] The next chapter reviews research to date on how people interact with the different components of domestic ventilation systems to try to understand whether ventilation practices are changing in relation to new technologies.

[59] Although beyond the scope of this thesis, now may be a good time to reflect on whether this is really desirable or even appropriate.

Chapter 3: Researching ventilation practices

3.1. Introduction

3.1.1. How can we investigate the ways people ventilate in low energy housing?

The previous chapter discussed how ventilation in low energy housing (LEH) is required to provide a balance between comfort, health and energy savings. Furthermore, it proposed that homes and their ventilation systems are part of a complex landscape of different social groups, policies, regulations, technologies and traditions. This chapter reviews the literature about both domestic ventilation 'behaviour' and 'practices'. The intention is to situate this thesis within the existing research and to identify both knowledge and methodological gaps relating to the understanding of how people are adapting the way they ventilate their homes in response to the introduction of new ventilation technologies.

Section 3.2 reviews quantitative research of how people ventilate their homes, to demonstrate that although these studies are essential in terms of describing the patterning of everyday consumption and highlighting certain research gaps, they cannot encompass the complexity of the whole system and therefore are unable to explain why ventilation is being done the way it is. Section 3.3 discusses socially oriented research into domestic life. The notion of ventilation *'practices'* is introduced here, beginning with a discussion of social practice theory (SPT) and then considering how this approach has been applied to the energy demand problem and domestic activities, and why it is an appropriate theory to underpin this thesis. Section 3.4 presents a summary of the chapter and sets out the theoretical framework, based on two authors' interpretations of SPT (Schatzki, 2002, Gram-Hanssen, 2011), which guides the data collection and analysis presented in this thesis. This is followed by a discussion of the research questions.

3.1.2. Researching energy consumption and people

The way we understand and investigate what people do varies between disciplines, where different conceptual frameworks and models are used to explain individual and societal phenomena. Understanding the role of people and societies in relation to reducing energy consumption has remained an important area of interest since the energy crises shook the 1970s, and prompted a paradigm shift in the *'definition of energy supply, from a solely technological problem to a bundle of social ones'* (Rosa et al., 1988, p.164). Although interest in this research area of '*energy conservation'* declined during the 1980s, it was revived towards the end of the 20th Century under the guise '*energy efficiency'* or '*energy saving',* when concerns about climate change and environmental issues became widespread (Martiskainen, 2007).

The Twin Rivers Project was one of the earliest studies to demonstrate how domestic energy consumption and people are connected. The study was conducted during the 1970s and found that the difference in energy consumption between the highest and lowest users in 28 nominally identical houses varied by more than two-to-one. Furthermore, when the residents in the household changed, so did energy consumption, suggesting that people, rather than intrinsic building fabric properties, were responsible for this variation (Socolow, 1978, Sonderegger, 1978).

A report by DECC and Chatterton (2011) reviews the most commonly applied theories and models of what the authors refer to as people's *'behaviour'*, with a view to informing energy policy. The report distinguishes between '*theories'*, as an abstracted way of understanding a phenomena, and *'models'* which are an attempt at simplifying reality so as to understand actual processes. The four main theoretical approaches are summarised in Table 9, below, and are discussed in sections 3.2 and 3.3.

Table 9: Social science theories of energy consumption[60]

	Disciplinary Theories	**Definition**
Individualist	Economic	Energy is a commodity and consumers will adapt their usage in response to price signals.
	Psychological	Energy use can be affected by stimulus – response mechanisms and by engaging attention.
Socially oriented	Sociological	Modern energy use is largely invisible, energy systems are complex, and daily practices are significant.
	Educational	Energy use is a skill that is learned through experience in specific situations.

3.2. Individualist studies of ventilation 'behaviour'

3.2.1. Introduction to individualist studies of energy use

Economic theory places the user at the centre of the decision making process and is governed by the *'economic-rationality model'* (Rosa et al., 1988), which assumes that pricing is the easiest way to predict and guide consumer choices. Behavioural economics is a field of enquiry that applies ideas from the psychology of decision making to economic theory. The main premise of behavioural economics is that people do not always make strictly rational and considered decisions, hence the flaws of the economic-rationality model, but instead perform a series of efficient mental shortcuts, or '*heuristics*', which '*ignore part of the information*' (Gigerenzer and Gaissmaier, 2011 p.451), to choose the action that will benefit them the most, with the least decision making effort.

Psychological theories accept that people are motivated by factors other than cost. Individual actions are still largely rational, or *'quasi-rational,'* but this time they are determined by a combination of our attitudes and intentions (DECC and Chatterton, 2011). The simplest models

[60] Compiled from DECC and Chatterton (2011).

assume that if people are given all the relevant information and acquire *'environmental knowledge'*, they will make a pro-environmental, or *'rational',* choice (Figure 14). However, this kind of linear approach was not found to be particularly effective in encouraging the desired actions, perhaps because it does not take into account attitudes, values, social norms and habits, which may also influence what we do.

Figure 14: Simple linear model of environmental 'behaviour'[61]

The Theory of Reasoned Action (TRA), introduced in Fishbein and Ajzen (1975), proposes that our intention to carry out a certain action is guided by a combination of a rational evaluation of the outcomes of that behaviour, and our beliefs about what others think, or more precisely, what we think the people whose beliefs we value think about that behaviour (subjective norms). A development of TRA is the Theory of Planned Behaviour (TPB), which includes an additional parameter, *'perceived behavioural control'* (Ajzen and Madden, 1986). The TRA has been used in research about household energy use (Seligman et al., 1979, Becker et al., 1981, Ritchie et al., 1981). More recently, Gill et al. (2010) have applied the TPB to a post occupancy evaluation (POE) study of 26 homes, which sought to quantify different types of energy 'behaviours' using an occupant questionnaire, and then compare the resultant scores with measured energy consumption at each dwelling. The results (based on responses from 18 occupants in 15 homes) show that in these dwellings *'energy-efficiency behaviours account for 51%, 37%, and 11% of the variance in heat, electricity, and water consumption respectively'* (p.491). This illustrates how, at best, models such as TPB can only account for part of what people do and that there is room for more holistic methods of understanding human activity.

Several psychological models have been developed specifically to address issues around sustainability and environmentalism. These include the '*Model of Responsible Environmental Behaviour'* (Hines et al., 1987), and Stern's Value-Belief-Norm theory of environmentalism (Stern et al., 1999). A limitation of all the aforementioned models is that they do not take into account habits and routines. Triandis' Theory of Interpersonal Behaviour (TIP) (Triandis, 1976) is based on a model which recognises the role of past behaviour and prioritises habits as critical in predicting future actions (COI, 2009). However, perhaps due to its complexity, this model has not been widely used in the field of energy consumption. The past is also considered in Kolmuss and Agyeman's *'Model of Pro-Environmental Behaviour'*, which seeks to explain the

[61] Adapted from Kollmuss and Agyeman (2002), p.241.

'value-action gap'[62] between apparent environmental awareness, or 'attitude', and the subsequent lack of pro-environmental behaviour (Kollmuss and Agyeman, 2002).

Numerous studies have been carried out which attempt to quantify and predict ventilation-related activities (see 3.2.2 and 3.2.3); however, unlike the literature reviewed above, these studies have tended to be atheoretical. Although the methodological and theoretical stance taken in these projects differs from that adopted throughout this thesis, their scope and findings were of relevance to the formulation of this study's research aims and questions; for this reason they are discussed below. The term 'behaviour' is used throughout this section to denote an individual's ventilation-related activity, as that is the term favoured by the authors of these studies. A limitation of these studies is that they consider how people ventilate in a purely positivistic[63] manner, despite using qualitative as well as quantitative methods to obtain the data. Furthermore, specific theories or models which had already been developed by contemporary research communities, such as those presented in the previous section, are seldom mentioned.

3.2.2. Measuring and modelling window opening

The first published study of domestic ventilation behaviour is presented in Brundrett (1977), who observes a *'strong association between temperature or external humidity and window opening'* in a study of 123 homes (Figure 15, see also Dick and Thomas (1951)). The author notes that British people have a tendency to open windows all year round, and identifies seven main *'reasons for open windows in winter'* (Figure 16). This early piece of research acknowledges the importance of occupants in influencing ventilation rates, indoor air quality (IAQ) and energy use; however, the study is presented as a technical investigation of building performance parameters, rather than as one based on social science research methods, despite using occupant interviews to '*elicit the person's own opinions and reasons for opening windows'* (p.290).

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[62] Term first coined by Blake (1999).

[63] This term is defined and discussed further in the Methodology (section 4.2).

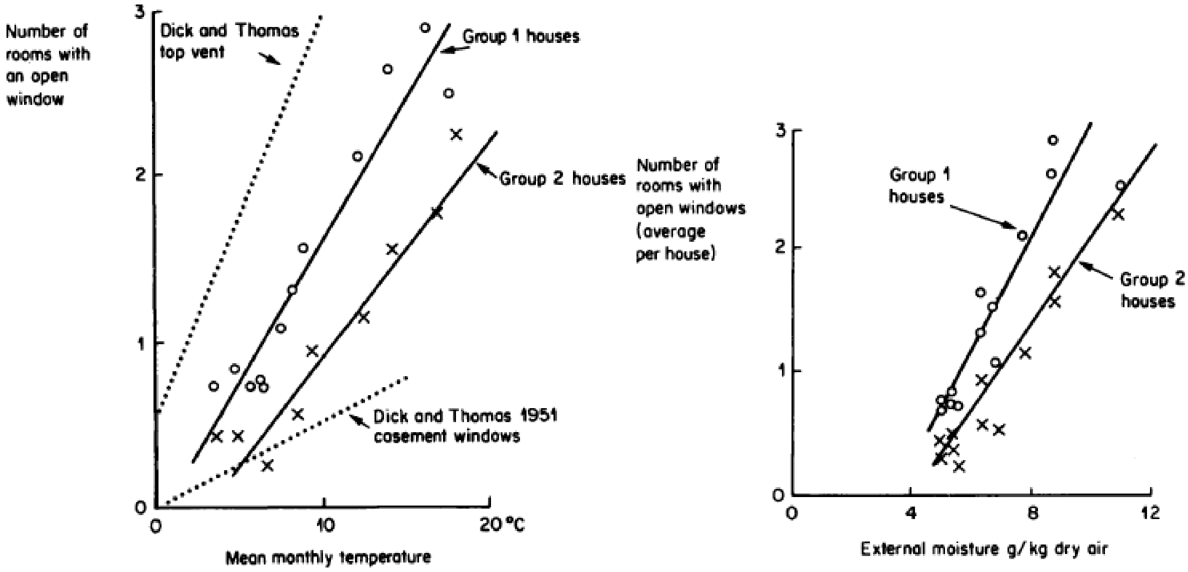

Figure 15: Window opening versus humidity and temperature[64]

Table V. Spontaneous reasons for open windows in winter

Factor	To freshen	To avoid condensation	To avoid stuffiness	To remove smoke	Too hot	Cooking smells	Air room
No. of mentions (max = 100)	68	31	20	14	9	9	5

Figure 16: Reported reasons for opening windows during winter[65]

A large scale study of how people ventilate was carried out during the 1980s under the International Energy Agency (IEA) Annex-8 project *"Inhabitant behaviour with regard to ventilation".* The findings are documented in the Air Infiltration and Ventilation Centre (AIVC) *"Technical Note 23"* (TN23), which presents the first conceptual framework for understanding ventilation behaviour (Dubrul, 1988) (Figure 17).

[64] Images from Brundrett (1977), p.290 (left) and p.293 (right).

[65] Table reproduced from Brundrett (1977), p.296.

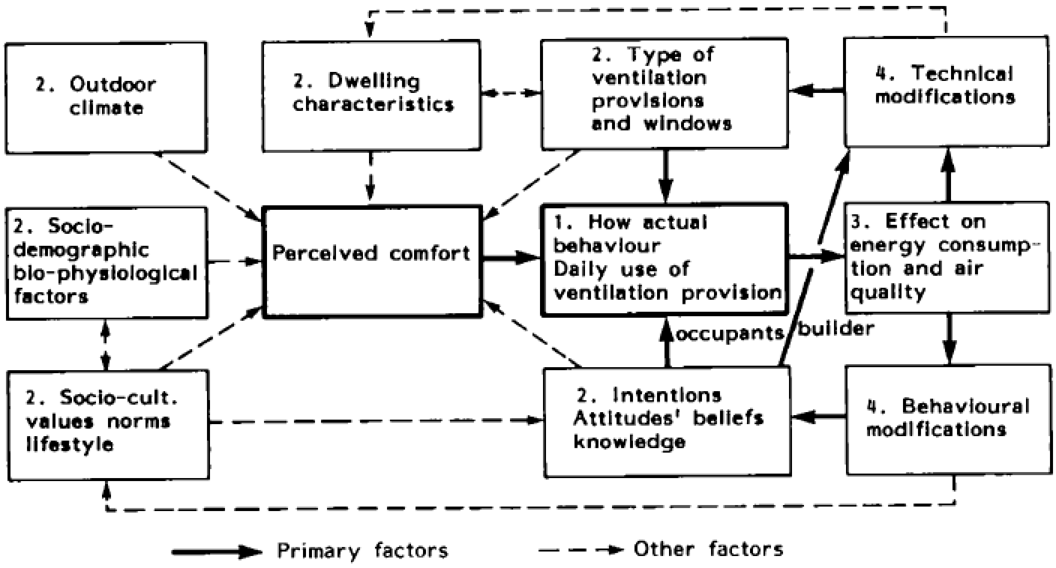

Figure 17: Earliest conceptual model of ventilation behaviour[66]

The findings can be grouped into the following four types, and are discussed briefly below:

- Correlations between window opening and other variables
- Impact of window opening on heating energy demand
- Variation in window opening in homes with different ventilation systems
- Attempts to reduce wintertime window opening through information campaigns

Correlations between window opening and other variables

These studies form the main findings of the (IEA) Annex-8 research. They try to identify why and when people open windows, generally by attempting to correlate certain *'factors'* or *'variables'* with either observed or self-reported window opening. A list of reported reasons for opening and closing windows was compiled in Dubrul (1988), while a wide variety of variables which relate to window opening are reported in Dubrul (1986). Van Dongen and Phaff (1989) divide these into *'climatological', 'human', 'environmental'* and *'architectural'* factors, while Dubrul (1988) groups them by *'dwelling fabric', 'lifestyle'* and *'weather'*. The range of variables identified in these studies is summarised in Table 10. These studies effectively communicate the complexity of domestic ventilation, as it is clear from the wide range of identified variables that predicting people's actions will be challenging.

Table 10: Factors influencing ventilation behaviour from IEA Annex 8

	Variables identified	Reference
Reasons for opening windows	Provide fresh air to bedrooms Remove cooking smells	Dubrul 1986 and1988

[66] Figure reproduce from Dubrul (1988), p.2.

	Remove cigarette smoke or stale air	
	Remove condensation or water vapour	
	Air the dwelling during domestic activities	
Reasons for closing windows	Save energy	
	Prevent draughts	
	Maintain preferred temperature	
	Presence of plants, pets or children	
	Protection from cold and rain	
	Privacy and security	
	Reduce noise and pollution	

Factors influencing ventilation behaviour (window use)		
Dwelling fabric	Type of dwelling	
	Orientation of rooms	
	Window design	
	Age of dwelling	
	Level of insulation	
	Heating and mechanical ventilation	
Lifestyle	Presence of occupants	
	Smoking behaviour	Dubrul, 1988
	Household activities	
	Attitude to energy saving	
	Indoor climate preferences	
	Moisture production	
Weather	Outdoor temperature	
	Wind velocity and direction	
	Sunshine	
	Precipitation (rain and snow)	
	Outdoor temperature	

Factors relating to window opening		
Climatological	Outdoor temperature	
	Orientation of windows with regard to sun	
	Orientation of windows with regard to prevailing wind	
Human	Indoor temperature preference	
	Energy consciousness of occupants	
	Smoking	(Van Dongen and Phaff, 1989)
	Fresh air preferences	
	Respiratory problems	
Environmental	Presence of condensation or mould	
	Moisture production in dwelling	
	Noise or odours annoyance from outside	
Architectural	Level of infiltration	

	Room volume
	Occupants' perception of mechanical ventilation

Dubrul (1988) reports a strong correlation between external temperatures and window opening (Figure 18). This is an example of the kind of complexity which is not captured by models such as the Standard Assessment Procedure (SAP), which assumes that in the heating period ventilation is independent of external temperature. The study also referred to an investigation of socio-demographic variables, which found that ventilation behaviour decreases with age of occupants. Figure 19 shows a plot of balcony door opening frequency against external temperature (Phaff, 1986). When the weather is mild and warm there is a strong overall correlation; however, the gradient is much shallower during colder periods, suggesting that during winter other factors may influence balcony door opening. Complementary findings are reported in Weihl and Gladhart (1990).

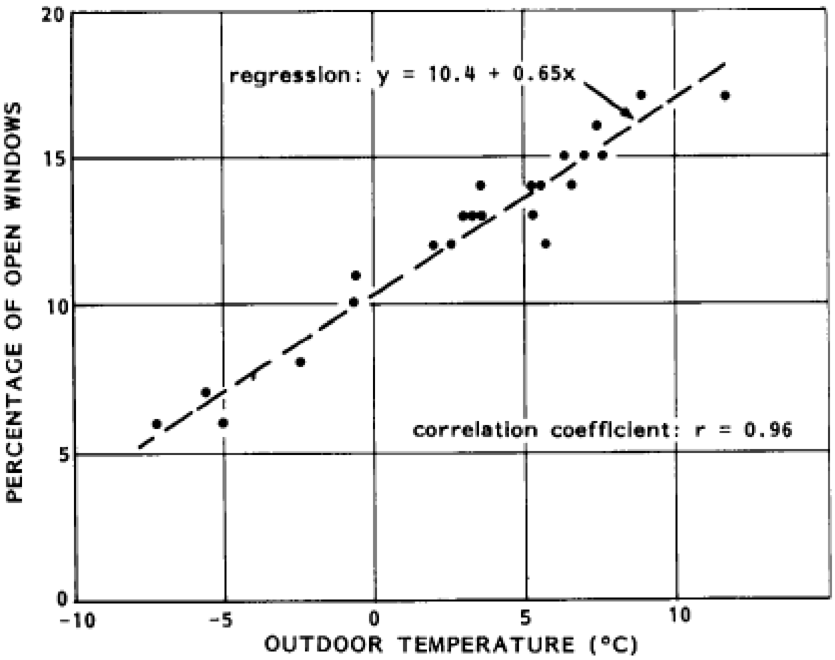

Figure 18: Outdoor temperature versus percentage of open windows[67]

[67] Reproduced from Dubrul (1988).

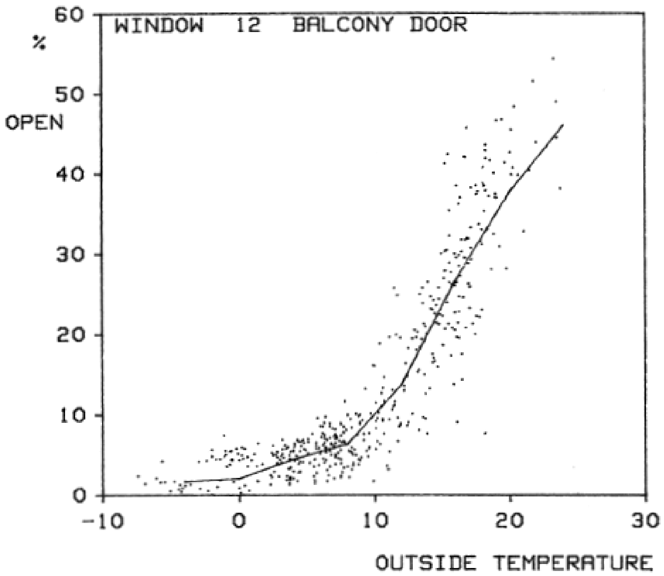

Figure 19: Balcony door opening versus external temperature (daily mean)[68]

Impact of window opening on heating energy demand

These investigations attempt to quantify the impact of opening windows on air change rates and, subsequently, heating energy demand. Phaff and van Dongen (1985) predict that 5000MJ/y of heat energy is wasted by opening windows, based on a sample of 80 homes from a single apartment block in the Netherlands. Kvisgaard and Collet (1986) calculated that 63% of a dwelling's total air change rate is attributable to occupant behaviour, based on study of 25 dwellings. Wouters et al. (1987) reviewed data from three studies to estimate the percentage of heat demand attributed to window use, based on three scenarios (Table 11). As insulation levels are increased (lower U-value) heat demand from window opening increases (in % terms); as current, new-build, average U-values are well below even the lowest of those measured here, awareness of this potential is all the more critical today.

Wouters and De Baets (1986) surveyed 2400 dwellings in Belgian social housing (via face-to-face questionnaires) and estimated that windows were open for 8% of time during winter and 35% in summer. The authors then estimated that the average increase in ventilation rate due to occupants is 0.26 ACH during winter and 1.5 ACH during summer. The previously introduced TN23 report, which reviews and summarises data from all the studies, estimates that a dwelling's energy use may vary by 10-15% depending on '*ventilation behaviour*' (i.e. window opening) Dubrul (1988). However, it should be noted that the figures presented in this section must depend on the permeability of the dwellings and therefore may not apply to contemporary low energy housing.

Van Dongen and Phaff (1989) investigated 279 single family dwellings in the Netherlands and concluded that energy use was more sensitive to window opening in living rooms than in

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[68] Reproduced from Phaff (1986).

bedrooms, as this was where thermostats were often located. They also reported that use of windows varied from room to room (Figure 20), with similar findings reported in Trepte (1986).

Table 11: Percentage of total heating demand attributed to window use in houses and flats[69]

U_m (W/m^2K)	T_i (°C)	Low window opening (%)	Average window opening (%)	High window opening (%)
Houses				
2.0	17	2	5	11
0.7	18	6	15	28
0.4	19	9	23	40
Flats				
7.0	18	5	13	25
1.4	19	15	33	52
0.8	20	20	45	64

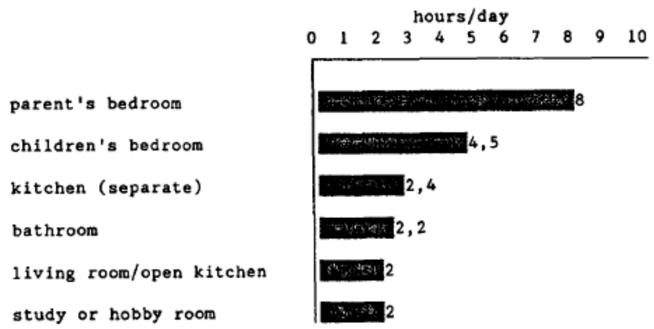

Figure 20: Heating season window opening by room type[70]

Variation in window opening in homes with different ventilation systems

The UK study conducted as part of IEA Annex 8 investigated 18 newly built terraced homes in London, all of which incorporated MV (Lilly and Makkar, 1986). Average window opening was lower than that reported by Brundrett (1977). The authors argue that this is explained by the presence of MV. The German study of 24 mechanically ventilated test apartments also found reduced window ventilation compared to naturally ventilated homes, by a factor of four (Erhorn, 1988).

[69] Adapted from tables 14 and 15 in Wouters et al. (1987), p.11.8.

[70] Reproduced from Van Dongen and Phaff (1989).

A study of the influence that type of domestic ventilation system has on occupant ventilation behaviour is reported in Van Dongen (1990). Questionnaires were distributed during a mild winter (~5°C) in 414 Dutch dwellings, comprising a roughly equal number of homes with natural ventilation (NV), mechanical extract ventilation (MEV) and balanced mechanical ventilation (MV). Different levels of window use were observed according to ventilation type, with the least use in dwellings with balanced MV and the most in NV dwellings, a finding supported by Lemaire and Trotignon (2000), who also found that approximately 72% of occupants reported regularly opening windows during the heating season, using a questionnaire study of 10000 households. By ventilation type, this figure increases to 76% for NV homes. However, residents of 64% of homes with balanced MV also claimed to regularly open windows during winter.

Reducing wintertime window opening through information campaigns

Phaff (1986) presents the findings of a study which attempted to measure the impact of information campaigns, aimed at reducing wintertime window opening, on people's use of windows in the Netherlands.[71] Before the second winter of occupation, written information about *'how to make proper use of the windows'* (p.57) was sent to 80 (out of 140) dwellings in the block, of which 20 dwellings were also visited in person. Window opening was measured using sensors. The results appear promising as, overall, windows were used less in the second winter monitoring period. In particular bedroom windows were open considerably less in the second year (70% less), while kitchen window opening actually increased by 13%. However, as it was on average 5°C cooler that year the effect of the intervention may be exaggerated. Also, the study does not distinguish between slightly and widely open windows; therefore, it is challenging to interpret the results of this kind of window opening monitoring data.

3.2.3. Interactions with ventilation systems

Simulating window opening

40% of participants in a postal questionnaire study by Lindén et al. (2006) reported that they were engaging in daily airing using windows (sample of 600 Swedish homes). This result supports many of the findings presented in the previous section which were based on research carried out during the 1980s. There seems to be general agreement within the literature that windows are being opened at times when it would be more efficient (in terms of energy) for them to be closed. Consequently, much of the more recent research around window opening is concerned with improving building simulation models to account for this; however, the work tends to rely on reported information (from buildings users) and measured environmental variables (e.g. Jian et al., 2011, Park and Kim, 2012). Use of window sensors is relatively rare, although some studies have incorporated sensor data into their investigations, albeit with much

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[71] Other findings from the same study are published in Phaff and van Dongen (1985) and Phaff (1986), and were discussed earlier in this section on p63.

smaller samples (e.g. Rijal et al., 2012, Andersen et al., 2013).[72] Also, research reported in Schweiker et al. (2011), measured the angle of window opening using a potentiometer.

A recent review of the literature on window opening behaviour in dwellings and offices, by Fabi et al. (2012), identified physiological, psychological, social, physical and contextual drivers behind ‘energy-related’ window opening (Table 12). With such a wide range of contributing factors the task of accurately simulating window-opening behaviour in a model is challenging, with inevitable simplifications and assumptions limiting the validity of results (e.g. Conan, 1982, Eftekhari and Marjanovic, 2003, Koinakis, 2005). Measured window opening data appear to be rarely used to develop simulation tools. However, even if opening data are collected they do not reliably predict the impact on ventilation rate or energy use.

Table 12: Factors influencing residential, energy-related window opening[73]

Physiological	**Psychological**	**Social**	**Physical environment**	**Contextual**
Age Gender	Perceived illumination Preferred temperature	Smoking behaviour Presence at home	Outdoor temperature Indoor temperature Solar radiation Wind speed Carbon dioxide concentrations	Dwelling type Room type Room orientation Ventilation type Heating system Season Time of day

Recently, a more sophisticated probabilistic approach has been adopted in several projects which attempt to simulate window opening in schools and offices (e.g. Nicol, 2001, Rijal et al., 2007, Haldi and Robinson, 2008, Yun et al., 2009, Dutton and Shao, 2010). Work by Sorensen (2011) used measured data to develop and test a probabilistic model of window opening behaviour in dwellings. The model considered environmental and climatic variables such as temperature and relative humidity (RH%), alongside building envelope parameters such as level of insulation and thermal mass to see if different designs were more or less robust to occupant interactions. A probabilistic model of domestic window opening behaviour is also proposed in Fabi et al. (2013).

Curtains and blinds

Opening and closing curtains and blinds can aid the prevention of excessive solar gains during summer and reduce draughts and heat losses during winter. Windows can also be covered and uncovered for other reasons, such as to admit natural light, to provide a view out or to maintain privacy. A small number of studies have considered whether, and to what extent, windows in

[72] The first of these references was based on a study of 30 homes and the second on a sample of 15 homes.
[73] From Fabi et al. (2012). Other physical environment factors could include temperature difference between indoors and outdoors and noise.

homes are covered at night time. For example, Lindén et al. (2006) note the '*reluctance among most households to cover windows by night with curtains or blinds'* (p.1924). Similar findings are reported in Carlsson-Kanyama et al. (2005), where the average questionnaire score was 2.1 (1 = never close at night, 5 = aways close at night) (based on further analysis of the same dataset). Interestingly, higher scores were reported by respondents living in apartments as well as those with low incomes. What is not clear, however, is *why* respondents drew curtains or blinds and whether energy saving, or, for example, matters of privacy, were involved.

A case study of two dwellings conducted by Ridley et al. (2014) revealed that occupants '*did not fully understand how to use the external blinds, or tilt the louvres'*, which had been provided for the purpose of summer shading. Consequently, the slatted components were not being utilised and the residents found that closing the blinds blocked the view and daylight. The study also mentioned the reluctance of residents to ventilate bedrooms using windows in summer, owing to spiders. Both of these factors can increase the risk of summertime overheating. These findings were based on a combination of in depth methods which included technical monitoring, an occupant questionnaire and walkthrough interviews with the residents.

Interaction with mechanical ventilation components

Several studies have found that people are not using mechanical fans as often as is recommended. For example, a large scale questionnaire study of over 5000 homes, by Price and Sherman (2006), found Californian homes to be under-ventilated; 30% of households *'rarely or never'* switched on the bathroom fan and a third of respondents experienced dusty, stagnant, humid or dry air. Furthermore, energy saving was one of the top two reasons people cited for closing, or keeping closed, windows. Park and Kim (2012) focused their investigation on 139 mechanically ventilated apartments in Seoul (supply and extract, unbalanced, no heat recovery). Almost 70% of respondents reported never used the ventilation during the heating season, citing concern over increased heating costs as the main reason for not doing so. In a questionnaire study of 7000 Dutch homes with MEV and mechanical ventilation with heat recovery (MVHR), 51% of residents responded that the ventilation system was turned on for less than three hours a day (Guerra-Santin and Itard, 2010). Instead, over 50% of people claimed to leave bedroom and living room vents open all the time and the majority of occupants use windows for several hours every day, even during winter.

A study by Soldaat and Itard (2007) conducted 18 interviews in Dutch homes with MVHR, alongside a theoretical modelling exercise, to try to quantify the energy impact of occupant ventilation. The interviews revealed that residents were largely unaware of the potential energy benefits of MVHR, or of the energy implications of wintertime window opening. During the summer the bypass mode was not being utilised, as most occupants were not aware of its existence. The authors quote a Dutch study which found that MVHR units are not being cleaned regularly enough in half of homes with the system. Similar findings are reported in Balvers et al. (2012). The findings of the modelling by Soldaat and Itard indicate that occupant interactions can negate the energy saving potential of MVHR, so that in some cases NV may be more energy efficient. A similar conclusion was also reached by Macintosh and Steemers (2005). 47% of the occupants surveyed across a new development of 59 homes kept the MVHR on the same setting all year, 40% on '*normal*' mode, 5% (2 users) on '*boost*' and one household had it disabled altogether. The study proposes that the main problem was lack of understanding of the MVHR system's intended operation. Misconceptions included the belief that windows should be opened to provide fresh air and the idea that using windows and MVHR together would increase the effectiveness. Misunderstanding of intended operation was also raised in Banfill et al. (2012) and Stevenson and Rijal (2008).

Lemaire and Trotignon (2000) report that over 25% of people in dwellings with MV regularly turn off the ventilation and that just over 13% of households admitted to blocking off aeration vents. More positively, over 60% of respondents claimed to clean the ventilation system once a year or more. The same study concluded that although ventilation type has little effect on satisfaction levels, the ability to switch off the ventilation returned increased satisfaction levels, especially among those people who seldom made use of this option.

Meyringer and Trepte (1986), report a German study which found *'a high probability of inhabitants rejecting or counteracting ventilation systems which do not comply with user expectations'* (Meyringer et al., 1987).[74] They identified the following six requirements for a ventilation system to meet user expectations:

- Avoidance of draught effects
- Tolerance of ill-attendance
- Minimal maintenance requirement
- Low noise level
- Freedom to interfere
- Familiarisation with a system

The aforementioned study also found that occupants perceived overheated inlet air as *'stale'* and *'not fresh'*. A weakness of this piece of work is that it fails to acknowledge any theoretical research in the areas of user acceptance and innovation which was being carried out at that time (e.g. Pinch and Bijker, 1984); this limits the scope of its contribution.

The results of a questionnaire conducted in Austria by Rohracher (2001) show that people in blocks of flats are significantly less satisfied with their ventilation systems than those in single family houses (Figure 21, Figure 22, based on 50 semi-structured interviews with residents and 144 completed questionnaires). The author interprets this by observing that *'owners connote this product with ecology, health and comfort, tenants rather stress ventilation systems being a*

[74] This reference is for a book published in German, which is currently out of print and not held in a UK library. The abstract is available at http://www.baufachinformation.de/literatur.jsp?bu=1987089040472.

modern technology', adding that *'the view of architects and planners best corresponded with the connotations of house owners' (p.299)*.

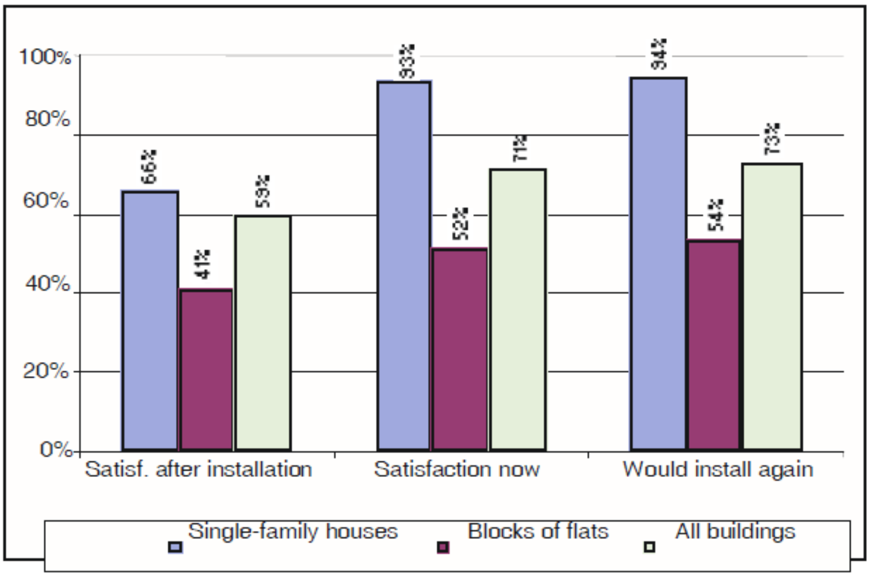

Figure 21: General satisfaction with ventilation systems[75]

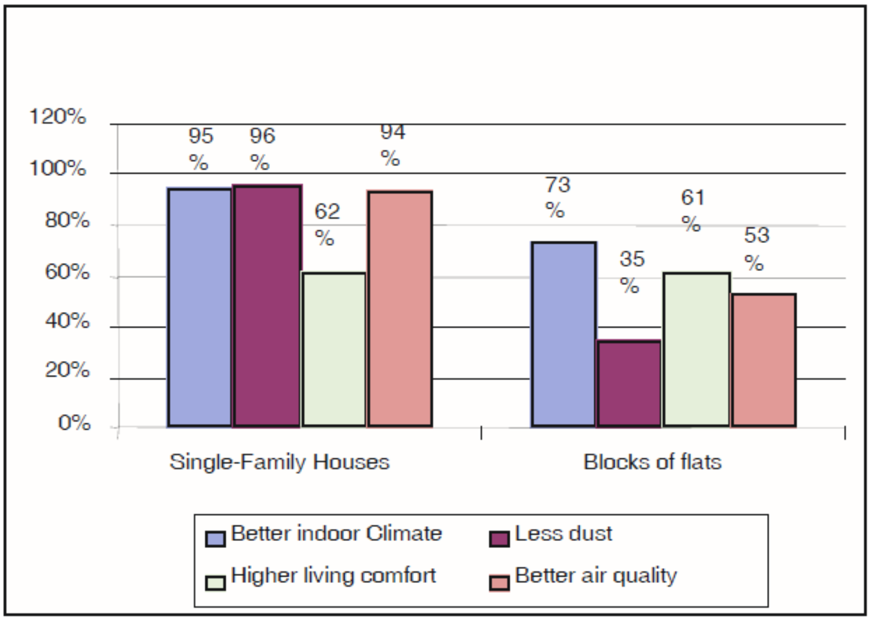

Figure 22: Benefits of living with MVHR[76]

Some of the reported problems included noise (40%), poor controls, and dislike of the *'(supposed) requirement to keep windows shut'* during winter (p.298), especially at night. Some people were found to be using supplementary heating devices and there were even those who sabotaged the system by blocking the air vents.

[75] Reproduced from Rohracher (2001), p.297.

[76] Reproduced from Rohracher (2001), p.299.

More recently, Brown and Gorgolewski (2014) conducted a POE study of four high rise apartment blocks in Canada using the Building Use Studies (BUS) Methodology questionnaire (ARUP, 2015) and semi-structured interviews. The study found that less than half of respondents were using their heat recovery ventilation (HRV) systems. The main reason for the under-use was acoustic discomfort and difficulty changing filters. Those people who had read the training manual were over seven times more likely to use the HRV, suggesting that a lack of knowledge may also contribute to the under-use. Furthermore, 76% of respondents from three of the blocks stated that balcony doors and openable windows were the primary source of ventilation during winter, compared to only 15% stating that it was HRV. This statistic corroborates the findings reported in section 3.2.2 that people frequently open windows during the heating season.

Introducing social dimensions to quantitative studies of ventilation

Certain studies have introduced socio-demographic dimensions into research about window opening. Dale and Smith (1985) concluded that concerns about health lie behind their finding that 13% of people in the UK sleep with the window open regardless of the weather.[77] The authors argue that 19th Century writings about hygiene and good housekeeping, such as those of Florence Nightingale and Mrs Beeton, have filtered down into the common conscious and shape contemporary beliefs, despite the fact the *'Miasma'* or *'bad air'* theories have been disproven and modern plumbing has replaced the practice of keeping a chamber pot under the bed (Baldwin, 2003, Johnson, 2006). A recent campaign by Age UK sought to encourage older people to close bedroom windows at night to reduce excess winter morbidity (Age UK, 2012), following research by Gascoigne et al. (2010) which found evidence of deeply held beliefs about the importance and benefits of leaving windows open at night.

A study by Fleury and Nicolas (1992) concluded that whether or not the wife stays at home and the presence and age of children are the main sociological factors affecting ventilation behaviour in the kitchen, bathroom and children's bedroom, while in the living room the orientation with respect to the sun is the main factor. The study also found that people tend to underestimate how long they open windows for, especially in the living room and master bedroom (Figure 23).

[77] The study also reported that 71% of respondents stated 'sometimes' and 17% 'never' in this questionnaire.

	Kitchen	Living room	Bathroom	Parents' bedroom	Children's bedroom
Overestimation	26	13	10	7	14
Underestimation	43	57	35	73	57
Rigth estimation	30	30	55	20	29

Figure 23: Percentage (%) of occupants over and underestimating window opening duration[78]

A follow up to the Twin Rivers project, this time with a focus on ventilation and occupant behaviour, is reported in Harrje and Kempton (1986). The paper considers the behaviour change potential of encouraging occupants to use the windows to provide cooling, rather than relying on air conditioning, during the summer. A blue light was used to indicate that the external temperature was below 20°C and that the air conditioning should be switched off and a window opened instead. The study was conducted in 40 homes in New Jersey over the hottest summer month (August). 10 homes received energy consumption feedback alongside the blue light warning, 10 received feedback only and 10 just the blue light, alongside a control group of 10 further dwellings. Results indicated that, at the end of the month long study, the homes with the blue light indicator (with or without feedback) used 15.7% less electricity than the control group, with the feedback alone having a slightly reduced positive impact; however, it is unclear whether this change was sustained over time. Encouraging passive cooling is increasingly relevant as parts of the UK feel the effects of climate change, and mechanical cooling becomes more prevalent in housing, as it has done in commercial buildings.

Another study reported in Harrje and Kempton (1986) used 12 open ended ethnographic interviews to investigate why people were opening windows during the heating season in an airtight apartment block (0.3 ACH) of 57 apartments. A follow up questionnaire was used to interview residents at 53 of the dwellings, with results indicating that 84% of tenants were using windows to reduce the effects of persistent overheating, compared to only 35% turning down the radiator valve. Windows were also being opened to provide *'fresh air'* and to reduce stuffiness. The questionnaire-interviews also revealed that tenants opened windows a small amount (10-15cm) to provide fresh air, and much wider to reduce temperature. The study demonstrated the need for understanding ventilation practices in the context of thermal comfort and heating provision, as they are clearly interconnected. Most of the residents felt that fresh air was healthy, something which the author's attribute to the fact that many of them were older people and would have grown up in homes heated by wood and coal, when opening windows would have been advisable to maintain a healthy IAQ. However, there were no younger participants in the sample to compare with the older people. A further interesting finding was that one of the reasons residents were using the windows instead of calling maintenance to ask

[78] Reproduced from Fleury and Nicolas (1992).

for help (29%), was that they did not want to be labelled *'complainers'* and risk losing their home; thus, opening windows became a more attractive solution, especially for lower-income residents. Finally, the study calls for increased research about the relationship between the building management and the housing authority, to understand why these inefficiencies were being allowed to proliferate.

A mixed method case study approach was also adopted in two further studies of residential ventilation behaviour (Diamond et al., 1986, Hainard et al., 1986). Diamond et al. used a combination of technical measurements of environmental parameters alongside an occupant survey of attitudes and behaviour towards comfort, IAQ, ventilation and energy consumption. Similar explanations for opening and closing windows were reported in Dubrul (1988), with the addition of painted or sealed windows inhibiting window opening, as well as health and the ability to *'maintain contact with the street'* being cited as reasons for opening windows. In contrast to other studies, windows were very rarely opened during winter. Possible explanations include the observation that many residents believed the building was cold and draughty, as well as the fact that the study was conducted in Chicago, where the winter design temperature is -22°C.

Hainard et al. (1986) carried out the first study of residential ventilation behaviour with explicit reference to the social sciences, at a case study site in Switzerland. Technical measurements were combined with occupant interviews in 15 apartments, to investigate *'psychosocial and cultural dimensions of the ventilation of an urban rented habitat' (p.12.3)*. The paper suggests that by understanding the *'underlying motivations'* of people's behaviour '*we should then be able to create suitable technically innovative improvements'* (p12.3). The quantitative data identified different patterns of behaviour in relation to external temperature, as well as according to storey and orientation of the flat. Attempts to triangulate these results with the survey data proved problematic. More interesting are the explanatory implications of the qualitative investigation; the study concludes that comfort expectations play a significant role in shaping window opening practices, but acknowledges the important contribution of other *'interactions'* and *'motivations'* related to window opening, as outlined in Table 13.

Table 13: 'Interactions' and 'motivations' for opening windows[79]

Diversity of 'interactions' in domestic ventilation
Existing infrastructure
Tenants' personal taste
Energy awareness
Technical knowledge
Thermal background
Habitual behaviours
Thermal comfort requirements
Window opening technique
Domestic motivations

[79] Table compiled using information from Hainard et al. (1986).

Ecological motivations Communication Health and hygiene Physio-psychological motivations
Diversity of 'motivations' for opening windows at home
Domestic motivations Ecological motivations Communication Health and hygiene Physio-psychological motivations

An important observation made in this paper is that interaction with the ventilation is *'diverse'* and shaped by the '*existing infrastructure'* which is outside of a person's control, as well as the personal preferences of occupants (p.12.7). Some interesting observations are made, such as the use of windows for communication (e.g. to supervise children) and of the '*instinctive*' and *'compulsive'* nature of window opening (p.12.12). However, the study lacks a theoretical underpinning which ultimately limits the usefulness and credibility of its findings. Theories are useful in social science as they can help locate a piece of research in the context of what has been studied before. Theories can also provide a vocabulary of concepts, categories and processes with which to investigate data and, in certain cases, with which to generalize findings beyond the specific study (Swanson and Chermack, 2013).

3.3. Ventilation as a social 'practice'

3.3.1. Critique of individualist approach

The theories and studies presented in the previous section share a conceptualisation of energy consumption as an individualist pursuit, *caused* by 'rational' actions which can be broken down, categorised and quantified. To date, much of the work about how people ventilate has focused on such individualist studies of behaviour. This is useful as it generates knowledge about the patterning of life and may be used to predict future actions. For example, the studies reviewed in section 3.2 highlighted potential trends such as the ongoing use of windows as primary means of ventilation despite the introduction of new technologies which, in theory, reduce the need for this activity, the relationship between certain environmental variables and occurrence of window opening, and the lack of engagement with mechanical ventilation components. What is missing from these studies is a way of understanding how change takes place at a societal level. Therefore, studies conducted from within this predominant, behaviourist, paradigm place a disproportionate emphasis on the agency of individual action, by positioning change as the sum of a multitude of individual actions, which can be influenced by 'factors' such as attitude, knowledge and beliefs.

This approach has also typically been relied on to inform policy (Jackson, 2005), despite numerous studies concluding that beliefs, attitudes and access to knowledge or information are not accurate predictors of a person's actions. For example, Bartiaux (2008) found no causal link between providing either generic or customised information about the environment and actually motivating homeowners to carry out energy saving improvements, and Crosbie and Baker

(2009) argue that '*people's general attitude towards environmental issues plays a rather minor role in their decision-making'*, and that instead they choose interventions that conform to their tastes and lifestyle expectations (p.77). By treating human activity as just another variable, which can be viewed and manipulated in isolation, these studies fail to address the complexity and interconnectedness which structures everyday life.

Shove (2010) offers a trenchant critique of individualist approaches, arguing that their status as the dominant paradigm for informing policy is political as well as theoretical. By placing emphasis on individual '*behaviour*', *'it obscures the extent to which governments sustain unsustainable economic institutions and ways of life'* (p.1274). A growing number of scholars are arguing that the individualist perspective is fundamentally flawed (Warde, 2005, Shove, 2010, Hargreaves, 2011, Shove et al., 2012, Foulds et al., 2013), as it fails to acknowledge the collective nature of human existence, and is unable to *'reveal interactions between physical and social systems'* (Chiu et al., 2014 p.4).

The previous chapter explained how the evolution of ventilation practices and technologies is best understood as a complex and multi-dimensional phenomenon. Social theories move away from individual 'behaviours' and consider collective, or 'social' practices as the '*unit of analysis'* (Shove, 2010 p.1279). Social research proposes that there is no such thing as typical energy behaviour, or, as Lutzenhiser (1993) puts it, *'consumption at the household level is neither homogenous or normal'* (p.249). Furthermore, energy consumption cannot be separated from everyday life and so a more holistic approach is needed to understand and influence it. The next section introduces social practice theory (SPT), and identifies this as an appropriate theoretical lens through which to investigate the use of domestic ventilation technologies in LEH.

3.3.2. Introduction to social practice theory

Reconciling structure and agency

A theory of social practice was first developed by Pierre Bourdieu and Anthony Giddens (Bourdieu, 1979, Giddens, 1984). According to Bourdieu, *'action is theorized as a culturally mediated response to structural constraints and change'* (Swartz, 1997). His work has been extremely influential across many disciplines; in addition to introducing the idea of social practices, Bourdieu developed the concept of social, cultural and informational *'capital'* as a distinct currency from economic capital, which can also be used by privileged members of society to gain advantage. The work of Bourdieu expounds social structures as influential determinants of human action.[80]

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[80] To clarify, it is not that Bourdieu disregards the agency of humans, but rather that he stresses the '*importance of agency within a structuralist framework'* (Swartz, 1997, p.98).

Over the last two decades Elizabeth Shove has contributed widely to the development of SPT in relation to research on sustainability and energy consumption (Shove, 1998, Shove, 2003, and Shove and Walker, 2010). In her latest book, Shove et al. (2012), explicitly align their position, in relation to the structure and agency dichotomy, with that of Giddens (1984) who writes the following:

> *'The basic domain of study of the social sciences, according to the theory of structuration, is neither the experience of the individual actor, nor the existence of any form of social totality, but social practice ordered across space and time' (p.2).*

Shove et al. (2012) critique individualist conceptualisations of energy consumption, which prioritise human agency and choice in driving behaviours and are grounded in *'rational choice theory'.* The authors argue that these are reflections of the utilitarian ideas of Jeremy Bentham, where *'action is, [….] explained by the pursuit of individual interests'* (p.2). Instead, SPT can *'transcend the dualisms of structure and agency' (*p.3).

What is a practice?

'Practices' are routinised and recursive activities which take place over space and time (Shove et al., 2012, p.6-7). Schatzki (2002) defines a practice as an '*organised nexus of actions'* (p.71), where actions are '*bodily doings and sayings'* (p.72). He notes several examples, include cooking practices, religious practices and banking practices. These are activities which are carried out in a multitude of different ways, in disparate locations and at varying times, yet they still share some commonalities which make them recognisable as part of that particular 'practice'.[81]

Social Practice Theory (SPT) supports a more holistic understanding of energy, technology and consumption than the individualistic studies of 'behaviour'. With SPT the main unit of enquiry is collective *'practice'*, rather than the individual energy *'user'*. A given practice exists independently from individuals, who are its 'carriers', and its components, or elements, cannot be understood as personal attributes (Shove et al., 2012, p.7).

Practices can exist as both 'entities' and 'performances'. The concept of practice as entity refers to the idea that '*a practice represents a pattern which can be filled out by a multitude of single and often unique actions reproducing the practice'* (Reckwitz, 2002, p.250). Following this, a practice entity can be interpreted as an 'ideal', 'typical', or 'normal' way of doing things, or as the sum of '*all the performances of a practice across time and space'* (Spurling and Blue, 2014, p.4). This second definition is more closely aligned with Schatzki's description of practices as '*complex entities joining multiple actions, projects, ends, and emotions'* (Schatzki, 2002, p.88).

[81] This is not to say that they cannot be part of other practices simultaneously; e.g. for some, banking activities may also be part of their working practices, studying practices or shopping practices.

The concept of practice as a performance relates to the instantiation, or bodily enactment, of the practice in question. As Warde puts it: '*Practices are thus coordinated entities but also require performance for their existence. A performance presupposes a practice'* (Warde, 2005, p.131).

Working with practices

Various authors have tried to break down SPT into more manageable components to inform empirical research. Some of the key perspectives of practice theory developed by these authors are summarised in Table 14 and are discussed below.

Table 14: Key elements in practices [82]

Schatzki, 2002		**Warde, 2005**	**Shove-Pantzar, 2005**	**Reckwitz, 2002**	***Gram-Hanssen, 2009***
Practical intelligibility	Practical understanding	Understandings	Competences	Body	*Know-how and embodied habits*
				Mind	
				The agent	
				Structure / process	*Institutionalised knowledge*
Rules		Procedures		Knowledge Discourse / Language	
Teleo-affective structures		Engagement	Meanings		*Engagements*
General understandings					
Entities		Items of consumption	Products (*Materials)*	Things	*Technologies*

Reckwitz (2002) distinguishes Social Practice Theory (SPT) from *'grand theory'*[83] (p.257), arguing that SPT is a framework for empirical social science used in *'analysis of the interconnectedness of bodily routines of behaviour, mental routines of understanding and knowing and the use of objects'* (p.258). Warde (2005), provides an early application of SPT to consumption studies, stating that *'consumption is not itself a practice but is, rather, a moment in almost every* practice' (p.137).

Shove defines a practice as the '*interconnected relations'* between three '*elements*': *'materials'*, *'meanings'* and *'competences'* (Shove et al., 2012, p.25). Although Shove has written extensively on theories of practice, the environment, technology and everyday life (Shove, 1997, Shove, 2003, Shove and Pantzar, 2005, Shove et al., 2009, Shove et al., 2012),[84] a limitation of her analytical method is that it often relies on historical data. This provides a rich and insightful account of how social practices, technologies and institutions have evolved in the

[82] Adapted from Gram-Hanssen (2008b). Text in italics and shading added by author. See 3.3.4 for a discussion of Gram-Hanssen's empirical work.

[83] The term grand theory refers to abstract and analytical theory building as opposed to theories based on empirical studies (Schwandt, 2007).

[84] Shove, 1997 refers to a conference paper which was lost in a computer error (personal communication with author) but has been cited by many scholars including Shove herself as the first record of the 'Materials, Meanings and Competences' framework.

past,[85] but it may not be so helpful for examining situational and local data such as that collected for this thesis. Furthermore, Shove's work places less of an emphasis on the structuring nature of material objects, and is therefore less useful for this research which places equal weight on the physical and social configuration of homes and their ventilation technologies.

In "The Site of the Social", Ted Schatzki introduces the notion of an *'arrangement'*, which is the *'hanging together of entities in which they relate, occupy positions, and enjoy meaning (and/or identity)'* (Schatzki, 2002, p.20). He describes four types of entities, as outlined in Table 15, below.

Table 15: Entities

ENTITIES	Human / man made	Non-human / non-man made
Living	People	Organisms
Non-living	Artefacts	Things

Entities and practices hang together in a mesh of 'arrangements' which 'order' the 'site' where social life takes place. Certain practices and entities are held together closely in 'bundles' of related activities, while others are more disparate. According to Schatzki's framework, the arrangement of physical artefacts and things (e.g. entities) helps facilitate or constitute social relations. One type of social relation is 'prefiguration'. Schatzki writes that '*the different components of arrangements enable and constrain one another's activities'* and that '*the site of the social prefigures the flow of activity by qualifying the possible paths it can take'* (Schatzki, 2002, p.44-45). This quote demonstrates how, in Schatzki's work, the physical and material fabric of the world plays an important role in structuring the activities that take place within it. This conceptualisation aligns with the socio-technical understanding of ventilation phenomena which was presented in the previous chapter, where the social and physical world is mutually constructed. The concept of groups of entities and practices being held together in arrangements, across a site, is illustrated in Figure 24. Schatzki's ideas have been pivotal in exploring the data collected in this research and were particularly influential in formulating the theoretical framework which guides this thesis, as discussed in 3.4.1.

[85] See, for example, Guy and Shove (2000), Chapter 5, for a discussion of how local, historical, cultural and commercial factors have influenced the take-up of insulation since the 1960s.

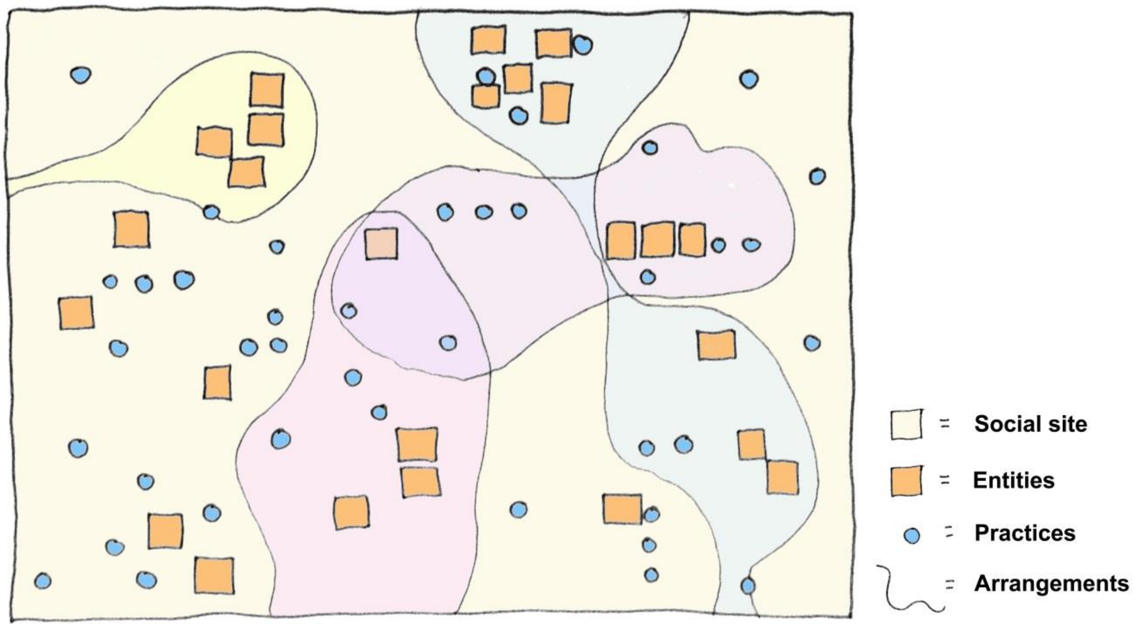

Figure 24: Concept diagram illustrating Schatzki's social 'site'

3.3.3. Technological transitions and Schatzki's concept of a 'flat ontology'

An additional contribution of Schatzki to the application of SPT to understanding technological transitions is the idea of a *'flat ontology'* (Schatzki, 2011). In order to explain the significance of this concept, some of the literature from Science and Technology Studies (STS), about technological transitions and innovation, must first be introduced.

STS

Moving consumption practices in a more sustainable direction is a critical issue for energy saving policy (Sahakian and Wilhite, 2013). Of relevance to this thesis is the application of ideas from STS to adaptation and social change in relation to new technologies. The key distinction in understanding societal transitions from such a perspective is that it should not be assumed that simply introducing a new technology will bring about widespread social change. Unfortunately, this view, known as technological determinism, is pervasive in today's policy landscape and throughout the construction industry. Nor can we follow the mantra of *'architectural determinism'*, a term used by Marcus (1999) to describe the individualistic notion that *'spatial environments determine the social arrangements, daily behaviours, and political status of those who inhabit them' (p.9)*. Instead, the research presented in this thesis aims to investigate how social practices and material arrangements coevolve and shape one another, or, how *'the site of social life prefigures the paths taken by the human activity that perpetuates and alters it'* (Schatzki, 2002: xix).

Rogers (1983) proposes a model of the '*diffusion of innovation*s' to describe the process by which innovations, such as a new technology, are diffused from the moment of availability to widespread adoption by society, via communication. Although this is now regarded as a classic model by some, Shove (1998) critiques Rogers' model for failing to acknowledge the potential for socio-psychological features to shape the actual form of the innovation. Rather, Shove argues, it perceives the social as a '*barrier*' to uptake, reinforcing the classic paradigm of technical determinism.

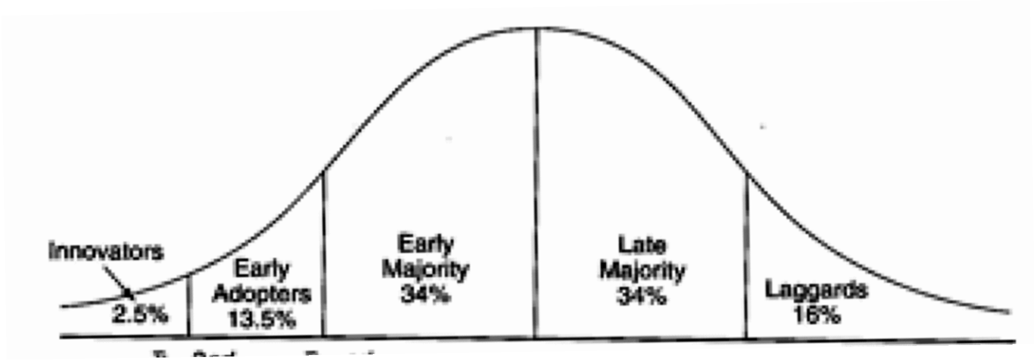

Figure 25: Diffusion of Innovations[86]

STS also offers the theory of the '*domestication of technology'* as a framework for understanding how technologies are introduced (Sorensen, 2006). Lie and Sorensen (1996) argue that it is useful to investigate the concept of domestication of technology from the users' perspective as their interactions with and manipulation of technical artefacts may result in the shaping of routines and practices. Gram-Hanssen (2008a) describes two historical examples of how routine domestic practices are not fixed; instead, they are continually evolving in response to new technologies entering the home. Firstly, the introduction of washing machines in the 1920s prompted an increase in the frequency and volume of laundry carried out by women (see also Cowan (1983)),[87] and secondly, the transition from communal to individual refrigerators had implications for the way families bought food and arguably facilitated the move towards suburban living, where there is often a greater distance between homes and shops.

According to Silverstone et al. (1992) a technology must pass through four stages on its journey to becoming widely adopted by individuals and society. These are Appropriation, Objectification, Incorporation and Conversion. Accordingly, domestication carries an implication of both individual and household choice. The dynamic of domestication is associated with the private use of technoculture in the home. This concept was initially proposed as a way of understanding how people integrate information and communication technologies (ICT), such as televisions, personal computers and mobile phones into everyday life, by looking at the roles and meanings that people ascribe to them (Haddon, 2006). A piece of work carried out as part of this PhD questioned the applicability of the domestication framework to WHV (Behar and Chiu, 2013).

[86] From Rogers (1983), p.247.
[87] Who could have foreseen that the introduction of time and labour saving domestic technologies would parallel a shift away from the tradition of domestic staff and increased expectations of comfort and service so that in fact the modern middle class housewife had more, not less work to do?

The resulting paper concludes that the assumed trajectory through the four stages is unlikely to take place in the UK social housing context:

> *'This analysis highlights the difficulty of objectifying a technology that one has not chosen to live with and that, in the case of PSV, may not actually be visible to the residents. Furthermore, we might question how easy it is for people to incorporate a new ventilation technology into their daily routines when existing and often deeply rooted patterns of use are still possible within the constraints of the new configuration. Perhaps it is no wonder that this analysis has not revealed a strong symbolic relationship between residents and their ventilation technology.' (Behar and Chiu, 2013, p.2398)*

However, the approach was useful as it allowed the authors to identify and reflect on some of the structural constraints which may hamper technologically driven attempts to change the ways people 'practice' ventilation. Furthermore, it raised the point that the notions of conspicuous consumption, which have been highlighted by other researchers in this area, do not apply to this particular context, where residents seldom explicitly choose the ventilation system in their new home. The work clarifies the need to examine the routine and everyday practices associated with ventilation, so as to find more meaningful ways to engage residents and designers in the transition towards sustainable living.

Critique of MLP

The potential to *'push'* the complex, dynamic and spatially disparate energy system towards a more sustainable path is proposed by Rohracher (2008), who references the multi-level perspective (MLP). This was introduced in Rip and Kemp (1998), and has been described as '*a framework for understanding sustainability transitions that provides an overall view of the multi-dimensional complexity of changes in socio-technical systems'* (Geels, 2010 p.495).

Figure 27 illustrates how the MLP addresses three different scales, or *'levels'*; 1) *'micro'* accounts for radical innovations generated in small *'niches'* of individual actors at a local level; 2) *'meso'* considers relatively stable technological regimes (status quo, rules and accepted assumptions); and 3) *'macro'* encompasses the whole socio-technical landscape which is slow to evolve (politics, worldviews, economy, demographics) (Rotmans et al., 2001). Rotmans et al. (2001) propose that governments can exploit the MLP to bring about '*structural change'* to society, using the historical example of the transition from coal to gas in the Netherlands' energy sector (p.15).

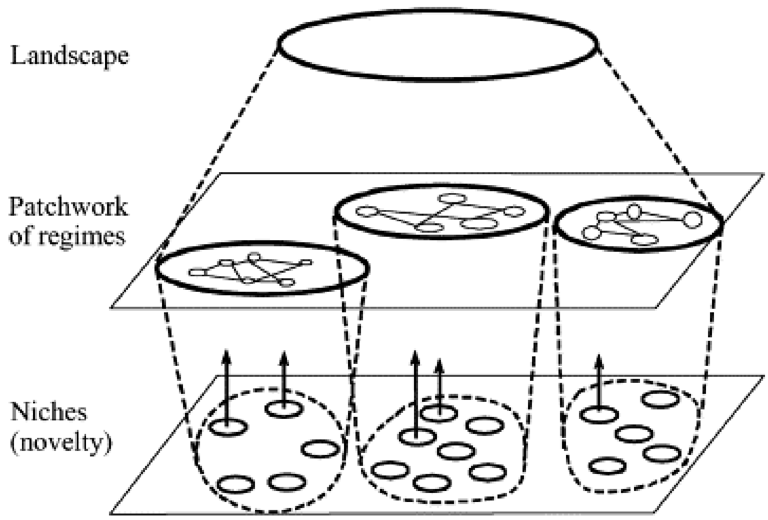

Figure 26: multi-level perspective of sustainability transitions[88]

However, Schatzki (2011) challenges the idea that transitions can be managed in this way and that change is simply a case of overcoming the '*non-technical barriers'* (Rotmans et al., p.30). He goes on to describe the MLP as '*ontologically suspect'* (p.15), because the space around the niches and regimes in each layer has the same composition as the niches, being made up of *'bundles of practices and material arrangements'* (p.2).

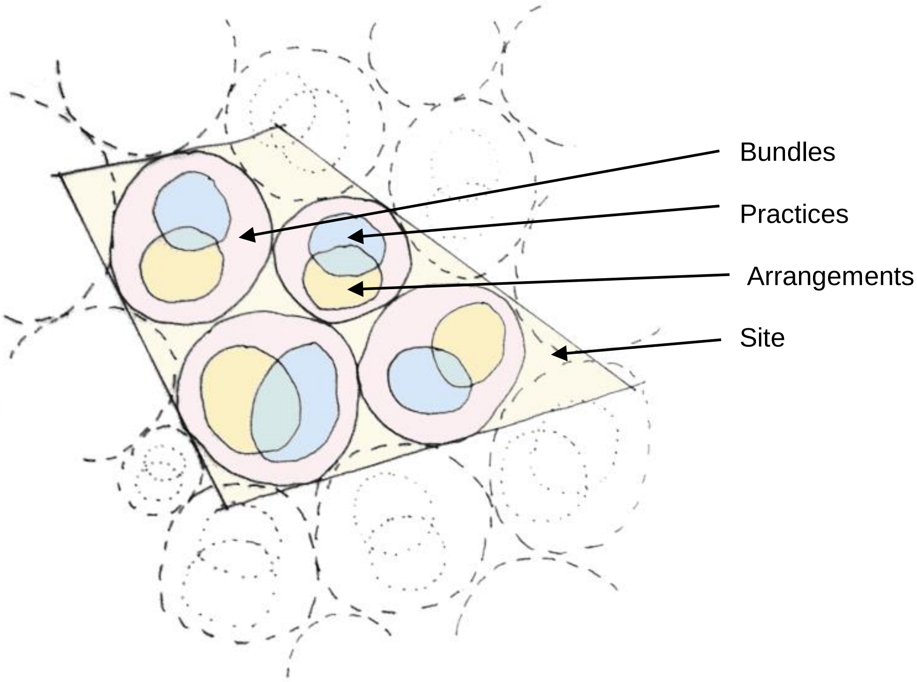

Figure 27: Conceptual diagram illustrating Schatzki's 'flat ontology'

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[88] Reproduced from Geels (2002), p.1261.

Schatzki argues that using a schematic such as the MLP therefore 'obscures' the reality of what is happening and causes confusion. Instead, he proposes that a flat ontology is a more useful approach to understanding '*how society can be moved onto a more sustainable path'* (p.3). By referring to a '*flat ontology'*, the social site can be understood as a slice of ever-expanding constellations of bundles, made up of interconnected practices and arrangements. This concept is illustrated in Figure 27 and contrasted with the MLP in Figure 28. While the MLP can be useful for understanding the historical development of large socio-technical systems, a flat ontology lends itself to a more detailed investigation of particular arrangements:

> *'There is only one way to understand social events, processes, and changes - by uncovering and studying the details [….] of real world cases' (Schatzki, 2011, p.24)*

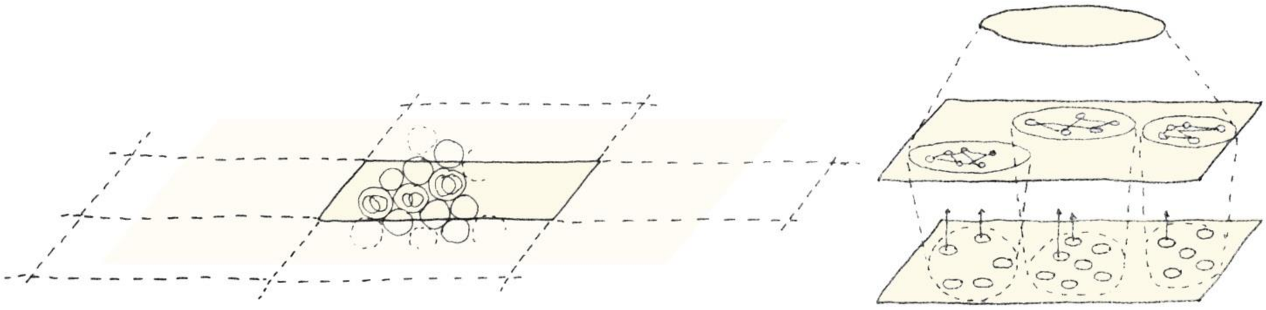

Figure 28: Comparison of a 'flat ontology' (left) with the MLP (right)

3.3.4. Research about domestic practices and energy efficiency

There is a growing body of empirical research that operationalises SPT to investigate issues of sustainability and energy demand. The theory has been applied to a wide range of topics, from hybrid car use (Ozaki et al., 2012) and Nordic Walking (Pantzar and Shove, 2010), to hosepipe bans (Chappells et al., 2011) and demand management (Strengers, 2011). Although these disparate topics may seem tangential to this research, the publications reveal a host of shared concerns, such as the inseparability of humans and non-human entities (e.g. car and driver, walker and poles, garden infrastructure and water suppliers), the examination of assumptions which may otherwise be taken for granted (e.g. separation of producers and consumers) and a focus on lifestyles and everyday activities as the unit of enquiry.

The most relevant group of published studies in this area are concerned with everyday household activities which relate to energy consumption. Kirsten Gram-Hanssen has carried out empirical studies of domestic energy consumption using SPT (Gram-Hanssen, 2008b, Gram-Hanssen, 2009, Gram-Hanssen, 2010). She has synthesised the various elements defined by other scholars as constituting social practices into her own framework, which comprises the following four components: 1) Know-how and embodied habits; 2) Institutionalized knowledge and explicit rules; 3) Engagements; 4) Technologies (see Table 14, p.64).

Gram-Hanssen (2008a) considers '*how routines change, develop and stabilize together with changes in social, cultural and physical structures'* (p.1184). Her work emphasises the importance of conspicuous consumption in homemaking and appliance purchasing. She discusses how people do not act in an economically rational way when they purchase a new home, for example preferring to replace kitchens and bathrooms before adding loft insulation or other energy saving measures. This, she suggests, is because '*one can dream of kitchens, talk about them and show them to others. Insulation of the roof* [or, for that matter, ventilation] *has none of these qualities'* (p.1184, text in square brackets added by thesis author). The work is based on qualitative interviews with householders about energy consumption and their daily lives. The paper divides routines into four groups: comfort (heating and lighting), hygiene (laundry), cooking (food preparation and storage) and ICT (communication and entertainment). It then examines the extent to which routines are *'influenced by the social or cultural structures of society'* and discusses how childhood norms, self-reflection and other people can influence routines in the home, while questioning the extent to which technologies and their infrastructures determine routine practices. For example, a discussion of radiator thermostats is used to illustrate how a technology, which was intended to replace a daily routine (manually switching heating on and off), is not always effective; some families do not understand it, some do not find it useful and others cannot agree on a comfortable setting and so they reject it.

Elsewhere, Gram-Hanssen (2008b)[89] focuses on heat comfort practices, highlighting several interesting observations relating to ventilation and airing. For example, the paper presents detailed descriptions of people's routines and habits and connects heating and airing as intertwined activities which share some collective elements between homes, such as a preference for warmer bathrooms and cooler bedrooms, a belief that fresh air is natural and healthy, as well as a tendency to air by opening windows, even when the heating is on and it is cold outside. It also reports individual experiences, such as that of a resident who likes to keep the living room warm (by closing the door to the hall when the heating is on), as, since serving in the army, *'he is allergic to cold'* (p.63).

The importance of understanding collective routines resonates with the cross-cultural ethnographic study of energy consumption in Japanese and Norwegian homes, reported in Wilhite et al. (1996). What can be understood as *'normal'* is actually deeply rooted in our culture and lifestyles, which may differ quite radically between communities. For example, while Norwegians *'tend to heat all rooms except for the bedroom'* (p.797), Japanese people use an individual under-table heater, or *'kotatsu'* to warm only themselves, as central heating is expensive and homes tend to be draughty.

Gram-Hanssen applies Schatzki's concept of spatial prefiguration (Schatzki, 2002), by explaining how participants conform to some of the expectations inherent in housing design; for example, they mostly slept in bedrooms on the first floor and spent the rest of their time on the ground floor, though the work does not go so far as to introduce the designers and builders of

[89] This conference paper was later developed and republished as Gram-Hanssen (2010).

housing into the discussion. Gram-Hanssen's more recent work explores how practice theory might be used to change routines and encourage more sustainable practices, first looking at household electrical appliances and standby consumption (Gram-Hanssen, 2009), and then reflecting on the three aforementioned case studies as a whole (Gram-Hanssen, 2011). This last paper argues that examining the four elements described in Table 14 (p.83), here defined as technical configuration, the family's social organisation, everyday routines and knowledge and engagement, can explain how some families were able to alter their practices after an intervention and why others were not. The paper then looks at how changes in an element of one practice may induce changes in other, overlapping practices which share this element (Figure 29).

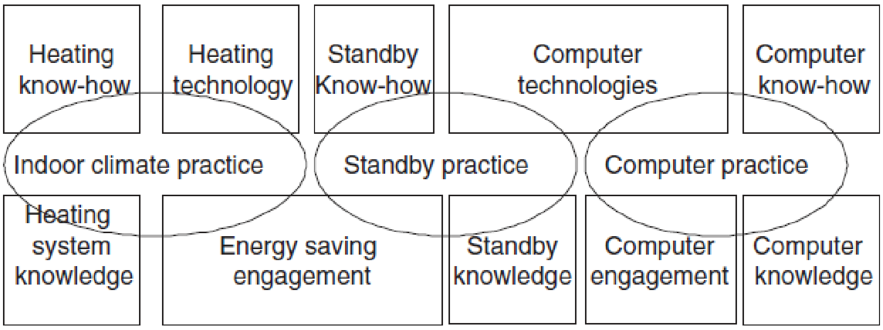

Figure 29: Three energy consumption practices which share connected elements[90]

Hargreaves et al. (2013) are also concerned with how practices might change. Hargreaves (2011) reports on an ethnographic study looking at attempts to encourage more sustainable practices in a commercial office; the work revealed that despite willingness by the *'Champions'* to change certain routines, health and safety and data protection laws prevented radical changes in the way waste was collected, and unreliable buses and the absence of cycle paths hampered employees' attempts to engage in more sustainable forms of commuting. Despite the Champions' ability to articulate how an alternative, more sustainable, practice may look in theory ('*practice as entity'*), they weren't able to actually materialise it into *'practice as performance'*.

Hargreaves et al. (2013) attempt to bring together the MLP and SPT, by identifying points of intersection between practices and regimes which they suggest are worthy of more detailed examination, to understand how sustainability transitions may be enabled and constrained. An important observation here is that *'incremental tinkering with existing systems'* will not be effective and that wholescale change needs to be instigated (p.407). Chris Foulds uses Gram-Hanssen's framework, combined with detailed building monitoring, to investigate the

[90] From Gram-Hanssen, 2011, p.74.

effectiveness of handover procedures at helping a group of residents living at a new PassivHaus[91] development adapt to the new material arrangement.

Foulds et al. (2012) question the extent to which technologies are used in the way the designers anticipate and suggest that changes in one of the elements of the practice can effectively destabilise or destroy it, leaving a void for new ways of doing things to fill. Although not specifically focused on ventilation, the presence of MVHR in PassivHaus schemes prompted a series of observations about ventilation in the context of energy consumption and maintaining comfort. For example, one family was found to have eschewed purchasing a certified PassivHaus cat flap and instead leave the door open, which led to greater heating energy consumption. Other *'unexpected'* activities included the family who felt that the effectiveness of the MVHR boost enabled them to purchase a deep fat fryer for cooking, whereas in their previous homes it would not have been possible (p.10). Another interesting discovery was that the residents who were most worried about moving into this new type of house engaged more with the handover induction and therefore actually grasped the concepts more fully than those residents who were *'complacent'* about the difference between their existing home and the PassivHaus (p.12); many of the latter ended up confused about how to maintain comfort. Although the importance of '*continual support and regular interaction* [was concluded to be] *vital to help them find their way through experiencing the technology' (p.19),* residents only contacted the registered social landlord (RSL) when they experienced a problem; therefore, it was hard for a meaningful and positive dialogue to be established between tenants and landlords as the first encounter was based around frustration and disappointment. Other issues with the handover process were the delivery of conflicting advice about window opening, and the fact that inductions were carried out when residents moved in during summer, so that by winter they had forgotten information they were given about maintaining comfort in winter.

Foulds et al. (2013) propose that by combining quantitative (monitoring) and qualitative (interviews about practices) data it was possible to reach a deeper and more meaningful set of conclusions than using either approach by itself would have obtained. This generated some particularly interesting insights about individual ventilation routines. For example, while one participant gave the impression during the interview that they were using the MVHR according to *'best practice'*, analysis of the monitoring data revealed that 'the *home was mainly ventilated through window opening rather than the MVHR settings' (p.629)*. Of particular relevance to this project is the treatment of ventilation not as a practice, but as part of numerous other practices, including: '*hosting guests (to improve air quality), thermal comfort (to change temperature), cooking (to eliminate odours), or washing (to remove water vapour)' (p.626)*. This hints at the

[91] PassivHaus refers to an optional housing standard that was developed in Germany. The key elements are a very well insulated fabric and such low airtightness that comfortable conditions are maintained throughout the year with minimal requirement for additional heating. MVHR is a mandatory feature of all new PassivHaus buildings.

complexity that may be anticipated in trying to study activities that form part of so many different practices, but also connects to the earlier discussion about how changes in one element of a practice may prompt changes in another which shares overlapping components (Figure 29). Finally, the paper acknowledges that the professional practices of architects and other institutional actors may also influence domestic practices, although this idea is not developed.

3.4. Discussion

3.4.1. Research framework

The first aim of this chapter was to present the key texts and theories in relation to the study of how people ventilate their homes. A second consideration was to explain how an appropriate conceptual framework was derived within which to conduct a piece of empirical research. There are many ways to study what people do. These can be broadly split into individualist studies of 'behaviour' and more holistic conceptualisations of social 'practices'. To date, much of the research about how people ventilate has focused on the former, highlighting a methodological gap around socially oriented studies of domestic ventilation, which this thesis seeks to fill. In particular, there is a lack of research into understanding why and how people's ventilation practices are evolving in relation to new technologies being present in the home, as well as about how WHV systems are incorporated into the design of new housing. Instead, the early studies focused on measuring the frequency of certain ventilation activities, perhaps with the intention of informing quantitative models of building performance.

Nonetheless, the individualist studies highlighted some important areas for further investigation. These include the observation that people seem to continue to use windows regularly even when living with a mechanical ventilation system, the relationship between window-opening and certain environmental conditions and the lack of interaction with MV systems. However, although evidently this kind of research is important in terms of describing the pattern of everyday life, this chapter has argued that for the purpose of this particular study, SPT provides a useful framework for investigating evolving ventilation practices.

The review of SPT literature presented a sophisticated set of concepts which are suitable for the study of a complex phenomenon such as domestic ventilation in LEH. The discussion of this theory highlighted how a person's daily routine is not only an expression of their individual choice, but also an enactment or performance which is constrained by the social structures within which that person is operating. The work of Gramm-Hanssen and Schatzki provided a set of concepts with which to develop a frame of reference for exploring ventilation practice. Firstly, Schatzki's work was drawn upon for the analysis of the physical arrangement of ventilation systems within the home (Chapter 5). The key concepts borrowed from Schatzki are prefiguration (constraint and enablement), and the idea that the socio-technical world can be understood as a landscape of practice-arrangement bundles (flat ontology). According to Schatzki (2002) '*prefiguration is, above all, the channeling of the physical causality that laces through the social site.'* Furthermore, *'an analysis of this phenomenon must take into account* *the operations of physical systems, the activities of organisms, and the efforts and constructions of humans'* (p.210-1), which this research seeks to achieve. Secondly, Gram-Hanssen's framework for empirical research into consumption practices was adopted as the primary theoretical lens for the analysis presented in Chapter 6. This provided a structure for discussing the range of activities which comprise people's everyday performances of domestic ventilation practices. Gram-Hanssen's framework conceptualises practices as a combination of the following four elements (Gram-Hanssen, 2011):

- **Know-how and embodied habits:** A practical and bodily understanding of doings, sayings and actions, generally embodied in routine and everyday activities.
- **Institutionalised knowledge:** Technical knowledge, cultural myths and rules, e.g. instruction manuals.
- **Engagements**: Meanings, morals and goals; that which is important to the practitioner.
- **Technologies:** The physical fabric of the building and the material 'artefacts' with which people interact.

Table 14 (p.83) shows how the two author's conceptualisations of practices are aligned and where they differ from one another. There is a distinct overlap between Schatzki's 'entities' and Gram-Hanssen's 'technologies'. However, Schatzki's 'entities' include all living and non-living things as well as those created by people. Furthermore, the physical arrangement plays a more prominent role in Schatzki's interpretation than 'technologies' do in Gram-Hanssen's work and was found to be useful for exploring the contribution of non-resident actors to the enactment of practices.

Gram-Hanssen's framework was adopted alongside Schatzki's ideas because it provides a practicable set of concepts which could be operationalised to explore the empirical data collected as part of this study. Also, as it was specifically developed to operationalise built environment and energy use research in housing, it is hoped that the terminology may be more accessible to a wider range of stakeholders.

Much of the existing work around changing practices takes a historical approach and has been able to benefit from hindsight; this luxury is absent in the climate change arena. Rather than study a historical period, this thesis is concerned with examining the current situation and transitions that are occurring now. The review of empirical studies using SPT illustrated how various scholars have operationalised the theory by breaking it down into components to facilitate analysis. It also revealed that to date there has been no specific study of ventilation in LEH in the UK conducted through the practice theory lens. This presents a distinct knowledge gap for this research to address.

3.4.2. Research questions in context

Chapter 2 presented evidence about how new WHV systems are being introduced into housing, as part of a set of design strategies aimed at reducing energy use, and how the physical configuration of homes is changing to accommodate these new technologies. These changes have seen the gradual introduction of new professions and different skills into the design and construction industries, creating a complex arrangement which relies on clear communication between stakeholders to succeed. The chapter argued that these design strategies are based on certain assumptions about the impact that introducing new technologies will have on building performance, assumptions which do not take into account the complex and unpredictable nature of the socio-technical interactions involved in ventilating a home. The chapter concluded that designing and delivering well ventilated and energy efficient housing within the constraints of today's construction industry is challenging.

Chapter 3 has argued that there is a gap in the knowledge around people's experiences of living with WHV in LEHs. Much of the existing research about how people interact with domestic ventilation technologies has been carried out from an individualist perspective, which fails to acknowledge the systemic constraints which structure the social and physical world. The chapter explored how a study of social practices could add to this body of literature, by questioning the assumption that technological innovation alone may be responsible for social change (Shove et al., 2012) and to help understand how people adapt (and do not adapt) to living with WHV. The chapter has also highlighted the need to examine the routine and everyday practices associated with ventilation, to find more meaningful ways to engage residents and designers in the transition towards sustainable living.

At this point it is worth reiterating the key aims of this thesis which are 1) to explore how residents of LEH with WHV technologies are ventilating their homes and to what extent their ventilation practices have adapted since living with WHV, and 2) to understand the potential role of various stakeholders, including architects, contractors and registered social landlords (RSLs), in enabling residents to adapt their ventilation practices to coincide with those which were imagined by the buildings' designers and which are required to meet current energy performance targets.

Following on from these aims and based on the theoretical framework outlined in the previous section, which was adapted from Schatzki and Gram-Hanssen's writings on SPT, the following four research questions are formulated:

> *Q1 How does the design and construction of homes with WHV systems create a physical arrangement which can constrain and enable residents' ventilation practices?*
>
> *Q2: How does the process of inhabiting a home conflict with residents performing ventilation as the designers intended and anticipated?*

The above questions are addressed in Chapter 5: The physical arrangement of homes with whole house ventilation. The physical context of dwellings with WHV is explored first, with reference to Schatzki's concept of prefiguration, so as to contextualise the occupants' enactment of practice, as well as to introduce the three case studies where data were collected.

> *Q3: How are people who live with WHV ventilating their homes?*

The above question is addressed in Chapter 6: Ventilation practices as complex bundles; routines, lifestyles and past experiences. The detailed exploration of activities relating to ventilation practices draws on the case studies presented in the previous chapter, and uses Gram-Hanssen's framework to analyse residents' reflections on living in, and ventilating, their homes.

> *Q4: How might interventions be constructed by different actors to help residents use ventilation as intended?*

The above question is addressed in Chapter 7: Disruptions for change, and draws on both Schatzki and Gram-Hanssen's versions of SPT.

Chapter 4: Methodology and Methods

This chapter sets out the methodological principles which have guided the research. Firstly, section 4.1 positions the research problem as an interdisciplinary one, which cannot be addressed in a monodisciplinary environment. Secondly, section 4.2 discusses how an interpretive research paradigm is the most appropriate perspective from which to undertake exploratory research into a poorly understood social phenomenon. Thirdly, section 4.3 argues for the use of case studies for conducting research into a complex, real world problem. This section also introduces the three cases selected for this study. Finally, section 4.4 presents the research methods used to collect and analyse data.

4.1. An interdisciplinary problem

4.1.1. Interdisciplinarity in energy demand research

Repko (2012) argues that interdisciplinary research is required to address certain complex problems, which are beyond the scope of a single discipline. A wider, more holistic approach is a particular strength of interdisciplinary research, which comprises:

> *'a process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline, and draws on the disciplines with the goal of integrating their insights to construct a more comprehensive understanding.' (Repko, 2012, p.15)*

Chapter 2 concluded that the current system of providing domestic ventilation in the UK has become extremely complex and that the delivery of a successful low energy home is not only a technical challenge, but a social one too (see 2.3.1). Furthermore, Chapter 3 argued that there is a research gap around the multidimensional problem of understanding how ventilation practices are evolving in low energy homes which incorporate various whole house ventilation systems (see 3.3.1). Although there are advantages to conducting monodisciplinary research, such as the ability to generate highly specialised knowledge that builds on a mature base of cumulative investigation, Lutzenhiser and Shove (1999) argue that the separation of social and technical research has limited the impact of social science on energy policy, and that an interdisciplinary approach to research would be beneficial. Also within the energy domain, Davies and Oreszczyn (2012) declare an '*urgent need for the formation of multi- and inter-disciplinary teams'* with '*diverse skills'* to address the decarbonisation of the housing sector (p.80), which, despite numerous technological advances and a plethora of research from a variety of disciplines, still accounts for over 25% of UK carbon emissions (Palmer and Cooper, 2013).

This thesis adopts an interdisciplinary stance. Interdisciplinary research lies *'between two or more fields of study'* (Repko, 2012, p.7). It is worth stressing the distinction of interdisciplinary, from multi-disciplinary work: while multidisciplinary research seeks to generate knowledge that advances several disciplines at once, interdisciplinary research is concerned with integrating findings in such a way that provides a deeper understanding of a complex issue; this does not necessarily contribute directly to all the individual disciplines from which it draws (Repko, 2012).

4.1.2. Disciplines contributing to this thesis

This research is located between at least three academic disciplines, namely architecture, engineering and science and technology studies (STS). Figure 30 positions these subjects within a conventional classification of the academic disciplines. The diagram illustrates how this research is connected to both traditional academic disciplines (social science) and newer, *'applied'* subjects (engineering and architecture). Each of these disciplines could also be understood as interdisciplinary fields of study which borrow from multiple disciplines (e.g. mathematics, physics, history and anthropology etc). These three disciplines form the foundation of the thesis, contributing (in various quantities and proportions) theories, methods, concepts and assumptions to the work (Repko, 2012). The author's own academic background is in the applied and professional disciplines of architecture and environmental design.

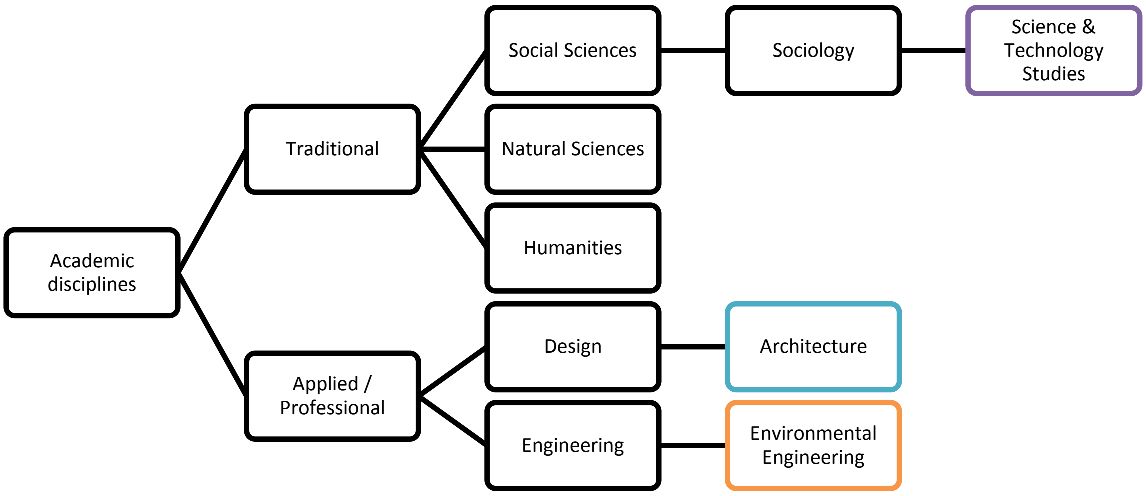

Figure 30: Academic disciplines[92]

Doing interdisciplinary research about energy and buildings poses an epistemological challenge, concerning the application of disciplinary knowledge and methods to applied research that does not always sit comfortably within a particular theoretical paradigm (Schweber and Leiringer, 2012). For example, this research adopts an epistemological perspective, theoretical framework and research methods that are more usually seen in the social sciences (see 4.2); however, it would not have been possible without an understanding of the design processes and assumptions made by building and construction professionals, nor without knowledge of the fundamental principles of environmental engineering which inform the design of low energy housing and its ventilation systems.

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[92] Adapted from Gutierrez (2015). Note: No 'energy' subject is included in this classification.

This is not an engineering project, nor is it a design endeavour. Energy consumption and environmental parameters were not measured, and the research does not make judgements on the suitability (or otherwise) of specific whole house ventilation (WHV) systems or strategies. Nor does it attempt to quantify the effect of different human actions or activities on energy consumption. Furthermore, no attempts have been made to design or even propose a 'failsafe' ventilation strategy, because such a thing could only exist in a laboratory and this work is concerned with real life buildings. On the other hand this thesis does not attempt to be a piece of 'pure' social science. Instead, the ambition is to integrate aspects of the social sciences with applied research fields to generate insights which could not be derived through a monodisciplinary approach. In carrying out interdisciplinary research, the author's role has been one that '*analyzes, synthesizes and harmonizes links between disciplines into a coordinated and coherent whole'* (Choi and Pak, 2006 p.351).

As concluded in Chapter 2, domestic ventilation is not as simple as the system design diagrams imply (e.g. see Figure 2, Figure 4, Figure 6 and Figure 9, p.38-44). A ventilation system cannot be separated simply from the building design or the people who occupy the space, and is therefore inherently complex and unpredictable. Consequently, the aim of understanding how ventilation practices coevolve alongside the introduction of new technologies, as well as the role of various stakeholders in enabling residents to adapt their ventilation practices, cannot be explored from a single disciplinary perspective. Instead, interdisciplinarity has been embraced as a way of integrating a range of concepts and tools; only thus can we address the complexity of an occupant's experiences of living with WHV.

4.2. An interpretive research paradigm

4.2.1. Introducing the philosophy of science

It is important to consider one's philosophical stance prior to presenting the findings of the research as this position guides the types of questions that are studied, the choice of methodology and the selection of appropriate research methods. In turn, the research questions, methodology and methods all influence the kind of knowledge which the work is able to contribute to the research community (Saunders et al., 2009). This section explains the underlying philosophical principles which have guided this research, and provides a justification for the use of the interpretive paradigm and a qualitative methodology.

While this research adopts an interpretivist approach, much of the literature on ventilation performance and behaviour which was discussed in Chapter 3, was conducted from within the positivist paradigm. These two perspectives are based on opposing ontologies (theories of reality) and epistemologies (theories of knowledge). The key differences between these positions are outlined in Table 16, below.

Table 16: Differences between positivist and constructionist research paradigms[93]

	Positivism - Postpositivism	Constructionism and Interpretivism
Ontology (What can we know?)	Realism/Objectivism: Reality exists independently from our experience.	Constructionism/Relativism: No absolute truths, world constructed by people, local and constructed reality.
Epistemology (How can we know what we know?)	Empiricism: Explanation/findings (probably) true, cause-effect linkages, facts and values can be separated, generalisations.	Interpretivism: Individual (normative) reconstructions/understanding, subjective values cannot be separated from research, time and context specific.
Methodology (What tools do we use to find out?)	Experimental/manipulative: Verification (or falsification) of hypotheses, mainly quantitative methods.	Qualitative: participatory methods, aims to interpret and understand social life and discover people's meanings.

4.2.2. Critique of Positivism

Ellsworth-Krebs et al. (2015) note that currently, positivism is the predominant research paradigm in energy demand research, an observation supported by Schweber and Leiringer (2012), who found that nearly 80% of literature relating to energy and buildings research is positioned from a positivist perspective. The key tenets of the positivist paradigm are espoused in the first few sentences of the abstract to a previously cited paper about domestic ventilation use (Maier et al., 2009). Here, we can see how the work promises to fulfil many aspects of the positivist paradigm; these include cause and effect (e.g. '*effect of ventilation systems in modern residential low energy houses on thermal and humid conditions'*), generalisations (e.g. '*influence of ventilation systems on human comfort'*), an experimental methodology, and quantitative data collection *(e.g. 'comprehensive experimental measurements'*). The dominance of this particular viewpoint, which is closely linked to the techno-economic paradigm,[94] prioritises physical realities over social ones. From this perspective, solutions lie in *'improving designs, technologies or other physical aspects of domestic buildings',* rather than understanding the social dimensions of homes such as '*comfort, identity, security* [and] *privacy'* (Ellsworth-Krebs et al., 2015, p.100).

Research conducted from within the positivist paradigm has made essential contributions to society. For example, Schrag (1992) notes that only by reducing the complex world to simplified variables have we been able to test the effectiveness and safety of life-saving new drugs. Furthermore, in the energy demand arena, research by engineers and building scientists has helped make buildings and appliances considerably more efficient by contributing to both technological innovation as well as new regulations and policies. However, Ellsworth-Krebs et al. (2015) note that the widely accepted performance gap between actual and predicted energy demand indicates that something critical is missing from our investigations. Their critique of

[93] Adapted from Sarantakos (2005),Denzin and Lincoln (2011) and Guba and Lincoln (1994).
[94] See section 1.1.1 for an introduction to the techno-economic paradigm.

positivism argues that seeking only technical solutions to performance issues is based on the premise that there is an ideal or 'intended' way to use the house, and that a building's users are merely 'passive' occupants responding to the built form (p.101). Hence, a proliferation of research advises improved design of controls or more usable interfaces, (e.g. Leaman and Bordass, 2001, Yao and Zheng, 2010), as a way to improve building performance. Instead, the authors argue for the *'recognition that home is both a social and physical unit'*, and that energy demand research should be broadened to take into account the complexity which ties together social and physical concerns along '*socio-technical lines of enquiry'* (Ellsworth-Krebs et al., 2015, p.102).

Elsewhere, positivism has been criticised for being overly restrictive; for example, generating hypotheses prior to conducting research means that interesting ideas falling outside of the key focus may be neglected (Sarantakos, 2005). Furthermore, by attempting to separate the research object from its context, this kind of research fails to address complexity; a key feature of real world problems (Clark, 2002). Finally, reliance on positivist research may reinforce the dominance of the techno-economic model of technology transfer which '*revolves around a faith in the replicability of proven scientific knowledge and a closely related belief in the economic logic of consumer behaviour'* (Guy and Shove, 2000, p.58).

4.2.3. A case for Interpretivism

Chapter 2 identified a knowledge gap surrounding people's experiences of living with WHV, the social practices that relate to these systems, and of the challenges people face in getting to grips with a new ventilation technology. Therefore, it was not felt to be appropriate to attempt to generate hypotheses, (of the sort which can be verified or falsified), about a phenomenon that hasn't yet been studied in sufficient detail to know what these hypothesis could be. Consequently, the research questions posed at the end of the literature review are exploratory in nature, seeking to understand the full complexity of people's experience of domestic ventilation both in physical and social terms.

These questions do not lend themselves to positivist enquiry, which is concerned with the search for objective truth and hypotheses testing through quantitative methods (3.4.2). Instead, a constructivist ontology and an interpretivist epistemology have guided this research, which is based on understanding individual experiences of reality rather than independently verifiable realities. From such a perspective the researcher and participants are 'co-creators' of the findings (knowledge) and the researcher takes a more active and visible role in the collection of data. As Strauss and Corbin (1990) put it:

> *'Concepts and theories are constructed by researchers out of stories that are constructed by research participants who are trying to explain and make sense out of their experiences and/or lives, both to the researcher and to themselves. Out of these multiple constructions, analysts construct something that they call knowledge'. (p.10)*

A constructivist-interpretivist approach is suited to a study which gives ontological priority to 'practices' and 'arrangements' as the primary units of analysis (based on Schatzki (2002), see section 3.3.2). As discussed in section 3.3, practices can be understood as socially constructed 'bundles' of everyday activities which are *'historically-culturally specific'* and based on *'collective, shared knowledge'* (Reckwitz, 2002 p.253), while arrangements are the '*hanging together of* [physical] *entities in which they relate, occupy positions, and enjoy meaning'* (Schatzki, 2002, p.20). Adopting an interpretive position does not mean rejecting the importance of the physical fabric of dwellings. The aim of this research is to broaden the investigation by taking a socio-technical approach, where social and physical entities are treated as equal components of a 'flat ontology' (see section 3.3.3).

4.2.4. A qualitative methodology

The choice of methodology was informed by the epistemological position. The interpretive paradigm welcomes individual, normative, reconstructions of reality, co-constructed by the researcher and the research subjects. Therefore, it is appropriate to use qualitative methods, where there is an explicit interaction and connection between researchers and their participants. Furthermore, as suggested in the literature review, social practices and arrangements are too complex and interrelated to be investigated separately from their context. One of the strengths of qualitative research is that it allows researchers to *'study people in their natural setting and attempt to make sense of phenomena in terms of the meanings that people bring to them'* (Dorsten and Hotchkiss, 2004, p.147). In this research, the use of a qualitative methodology aids the collection of rich, detailed and contextual data about individual experiences of living with WHV.[95]

Although qualitative research is now accepted as an important social science research method, Morgan (2007) points out that between 1960 and 1980 quantitative research dominated the social sciences; however, over the last 30 years the use of qualitative research has been embraced by a number of disciplines. Despite this, there are still a number of criticisms which are directed towards qualitative research, as summarised in Table 17 below:

Table 17: criticisms of qualitative research[96]

Efficacy	Hard to study relationships between variables with the degree of accuracy required to inform policy.
Representativeness and generalisability	Based on small samples and therefore is hard to make generalisations from findings.
Objectivity of interpretations	Without objectivity there is no way of knowing whether the researcher has captured the true meanings of the respondents' words.
Validity and reliability	Validity and reliability are concepts based on statistical research and cannot be ensured with qualitative research.
Time and cost	Qualitative research is time consuming and therefore expensive. Large amounts of useless data may be produced, wasting more time.

[95] Specific methods are discussed in section 4.4.
[96] Adapted from Sarantakos (2005), p.45.

Comparability	The data produced in qualitative research cannot easily be compared.
Replicability	The nature of the research methods makes it impossible to accurately replicate a study.
Ethics	Conducting research that involves close contact with participants can raise ethical concerns.

However, some of these challenges can be overcome so that qualitative methodologies can also be used with rigour. For example, instead of seeking 'validity' and 'generalisability', qualitative researchers are concerned with *'authenticity, goodness, verisimilitude, adequacy, trust-worthiness [and] plausibility'* which can be checked using, for example, *'triangulation, thick description, and peer reviews'* (Creswell and Miller, 2000, p.124). Furthermore, as discussed in the previous section, not all research is concerned with objective truth. In this thesis, a study of social practices within socio-technical arrangements requires a detailed understanding of everyday life, something which cannot be reduced to quantitative variables or parameters. Therefore, in this case, qualitative research enables the study of a phenomenon in a way which would not be possible using quantitative methods.

Despite the challenges of qualitative research, the only way one can really begin to unpack the question of how ventilation practices are constrained and enabled by their surroundings, is through the use of a qualitative methodology, where the gathered data are closer to reality and the research field than those collected using a quantitative methodology (Sarantakos, 2005). This way, the research community can begin to understand such a complex phenomenon.

4.3. Case study research design

4.3.1. Making the case for cases

Definition of case studies in research

Robson (1993) notes that a case study is *'a strategy for doing research which involves an empirical investigation* [….] *using multiple sources of evidence' (p.178).* This is a useful definition as it positions case studies not only as a source of data, but as a type of research strategy which can inform the way data are collected. Yin (2009) argues in favour of using case studies in certain situations, arguing that they are the most appropriate strategy '*when "how" or "why" questions are being posed, when the investigator has little control over events, and when the focus is on a contemporary phenomenon within some real-life context' (p.2).* Furthermore, according to Warde, there are two questions which are defined as being critical for understanding social practices. These are: '*Why do people do what they do?'*, and **'***How do they do those things in the way that they do?'* (Warde, 2005 p.140).

The work presented in this thesis is closely aligned with the above three quotations; case studies are used as a research strategy for investigating a contemporary phenomenon, namely whole house ventilation (WHV) in low energy housing (LEH), within its real life context. The case studies also guided the collection of empirical data from a variety of sources, relating to the three WHV systems which are 'approved' in the building regulations: 1) mechanical extract ventilation (MEV), 2) mechanical ventilation with heat recovery (MVHR) and 3) passive stack ventilation (PSV).[97] Furthermore, the research questions addressed in this investigation all seek to answer 'how' and 'why' certain practices occur.

In the literature, case studies are more usually defined in terms of their characteristics (Table 18) Other researchers, e.g. Wievorka (1992) in Ragin and Becker (1992), go even further, suggesting that a case can also be regarded as a theoretical construct, which is not necessarily defined at the outset of the research but may emerge from the findings. In this thesis, cases are understood as complex bundles of practices and arrangements, as well as a source of data.

Table 18: Key characteristics of a case study[98]

Key characteristics of a case study
• Empirical research • How and why questions • Unable to control events • Contemporary phenomenon • Real life context • Multiple sources of evidence • No clear distinction between phenomenon and context • Single or multi-case

Misunderstandings about case studies

One of the criticisms levelled against case studies is that they are largely descriptive and cannot be used to attribute causes; instead they should focus on exploratory tasks such as generating hypotheses (Shavelson and Towne, 2002). In this instance, case studies could only form the first stage of a larger piece of research, rather than acting as a strategy for informing the whole project. However, Yin proposes that case studies can be exploratory, descriptive *and* explanatory, as can experimental (e.g. quantitative) research designs (Yin, 2003).

Another common misconception about case studies is that, as a single case or a small sample of cases cannot be used to make global generalisations, they are unable to contribute towards scientific knowledge. However, Flyvbjerg (2006) dismisses this criticism and argues that grappling with cases is an essential part of the human learning needed to gain mastery of a subject or phenomenon. Therefore, he advocates the use of *'thoroughly executed'* case studies to strengthen the discipline of social science (p.219). Furthermore, the closeness of case studies to real life situations makes them ideal for the *'development of a nuanced view of reality, including the view that human behavior cannot be meaningfully understood as simply the rule governed acts found at the lowest levels of the learning process'* (Flyvbjerg, 2006, p.223).

Yin (2003) argues that multi-case studies can be used to '*expand and generalize theories'* rather than make statistical generalisations (p.10). The use of multiple cases to explore a single phenomenon enables some comparison to take place between cases to see whether findings are isolated and unique or repeated across cases, creating more *'robust'* and *'compelling'*

[97] The three systems were described in section 2.2.5.
[98] list compiled from Robson (1993), Saunders et al. (2009), and Yin (2003).

arguments (p.46). As discussed in 4.2.2, statistical generalisation is not the primary aim of this research. At the outset, insufficient knowledge had been published about the research topic to generate hypotheses for testing using experimental or quantitative research methodologies. Instead, exploratory research was planned and conducted, in order to provide insight about a complex phenomenon. Only when a significant body of exploratory and case study research is available to draw on could a generalizable study be planned and executed. It is hoped that this research might contribute to such future undertakings.

Case studies have also been criticised for a lack of objectivity and tendency towards bias, as researchers may select cases to confirm their own preconceived views. However, according to Flyvbjerg (2006), a number of studies have shown that researchers typically report being forced to revise their assumptions and challenge any initial hypotheses after undertaking case study research. Furthermore, researcher bias is not inherent to case study methodologies but may occur in any piece of work when high standards of research practice are not adhered to.

As practices are so intrinsically connected to their everyday context, it would be difficult to conduct a study of domestic ventilation practices in an 'experimental' laboratory setting, where all variables can be isolated, controlled, and modified.[99] By removing the very context which it seeks to investigate, a controlled experiment would create a crude oversimplification of the phenomenon. Instead, this research is concerned with understanding people within their real life domestic settings, to learn more about contemporary ventilation practices against a backdrop of evolving housing design. Case studies are well suited to this kind of work as they allow researchers '*to gain a rich understanding of the context of the research and the processes being enacted'* (Saunders et al., 2009, p.146).

4.3.2. Practicalities of working with cases

Criteria for choosing cases

Selection of appropriate cases is very important so that they are able to contribute useful insight about the research topic. In this research, three cases were selected at the outset of the study to represent three different WHV strategies (the selection and composition of the research 'case' are discussed in the next two sections).[100] This is defined by Flyvbjerg (2006) as *'information oriented selection'*, where cases are chosen based on some expectation of the information they might contain (p.230). Deliberate and considered selection of cases allows the qualitative researcher to uncover the most revealing insights about the research topic (Mabry,

[99] If such a study were to be attempted, the findings may reveal 'practices relating to taking part in an experiment' which are unlikely to be the same.

[100] In this sense, this thesis is aligned with much of the work carried out in the discipline of environmental engineering and energy demand research which was presented in the literature review: for example, POE is an example of case study research.

2008).[101] Furthermore, the use of 'critical' cases is a way of increasing the credibility of a study (Flyvbjerg, 2006). In this thesis the decision was made to try and select exemplar cases, which were procured by competent design teams and which followed best practice procedures. With this strategy, it could be expected that many of the issues identified may also be present in more conventional and less ambitious construction projects.

The main criterion for selecting case studies was breadth. The aim was to explore a wide variety of WHV systems. One case was chosen for each of the three WHV ventilation systems outlined in Approved Document F (ADF) of the building regulations: Passive stack ventilation (PSV), mechanical extract ventilation (MEV) and mechanical ventilation with heat recovery (MVHR) (HM Government, 2010a). It was hoped that by covering the full range of 'approved' systems, many of the technologies and components which will be found in future LEH would be encountered.

The selection of cases was based on opportunistic sampling and relied on the following conditions:

- ***Supportive gatekeeper:*** This was required to help gain access to the homes for fieldwork and to provide design documentation, reports and other information relating to the cases.
- ***Accessibility:*** Cases had to be accessible from London within the allocated research budget.
- ***Availability of monitoring data*:** It was hoped that access to monitored data about energy consumption and environmental performance would be available for secondary analysis and to develop a richer context of the schemes.

Selection of cases

Academic and professional contacts were used to identify recently completed housing developments which had used one of the three targeted ventilation systems and which could form the basis for case studies. Once project was suggested by a supervisor, another by an academic colleague and the third by an architect whom the author met at a conference. Each of the three housing developments is managed by a registered social landlord (RSL), who was found to be supportive of the study and willing to help.[102] One case is located in Central London, one in Surrey and the third approximately 75 miles away from London in an underdeveloped suburban area. All three developments have participated in some kind of post occupancy

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[101] This is often referred to as purposive sampling; however, the term sample suggests a statistical affiliation which is not deemed appropriate here.

[102] In 2008 RSLs owned 9% of housing in the UK, while councils also owned less than 10%. Altogether, this housing tenure makes up almost 20% of our housing stock (Palmer and Cooper, 2011, p.18).

evaluation (POE) work. The three cases provided a breadth of WHV systems with some POE data, were accessible from London and benefitted from a supportive gatekeeper who helped provide contacts and access.

A requirement which applies at all multi-case studies is that '*the objects of investigation are similar enough and separate enough to permit treating them as* [qualitatively] *comparable instances of the same general phenomenon'* (Ragin and Becker, 1992, p.1). Some key differences and similarities between the cases are presented in Table 19. Overall, it was considered that the three cases are sufficiently similar to facilitate meaningful exploration of domestic ventilation practices, whilst providing access to a wide breadth of ventilation systems, design processes and dwelling types. This was important so that the findings might be of interest to a wider audience, beyond those involved in the specific cases.

Table 19: Key similarities and differences between cases

Similarities	Differences
WHV present	Three different WHV systems investigated: MEV, MVHR and PSV
Ventilation system new to residents in majority of homes (one exception)	Compliance with different versions of ADL and ADF owing to varying years of completion
Low energy design features	Varying levels of low energy and sustainability aspiration
POE carried out at all cases with some data available	POE data not directly comparable - different variables measured over different time periods
All procured under design and build contracts	Different years of completion: 2005 (MEV), 2008 (PSV) and 2011 (MVHR)
Contextual similarities: • All suburban locations	Contextual differences: • Case B is all flats, Cases A and C contain mix of terraced and semi-detached houses • Differences in design team composition - one project by major housebuilder/developer, others smaller organisations and bespoke design • Demographic groups range from single person households to a large, tri-generational family
All RSL managed properties, purpose built for the landlord	

Composition of cases

The main units of analysis in this research are ventilation practices, as a form of social practice. However, as discussed in Chapter 2, social practices are inseparable from their context and need to be investigated within a more holistic socio-technical arrangement comprising different types of entities. Therefore, in order to understand practices relating to ventilation, it is not sufficient to look at only the residents. Instead, a wider boundary is drawn around each case to include the physical arrangement of the homes. Furthermore, to try to understand how those arrangements came to be the way they are, other human and non-human entities who were involved in the design and construction of the dwellings, are also considered.

The three cases which were investigated are:

Case Study A: Mechanical extract ventilation within prototype sustainable housing

Case Study B: Mechanical ventilation with heat recovery at a large scale regeneration project

Case Study C: Passive stack ventilation at an urban terrace

Each of the three cases is conceptualised as a socio-technical arrangement, comprising, to use Schatzki's terminology, *'humans'* (e.g. residents, architects contractors and RSLs), *'non-human entities'* (e.g. household items), *'artefacts'* (e.g. non-living human made objects) and *'things'* (e.g. air, water, weather, light) (Schatzki, 2002) (see Table 15 (p.82) and Figure 31, below).[103]

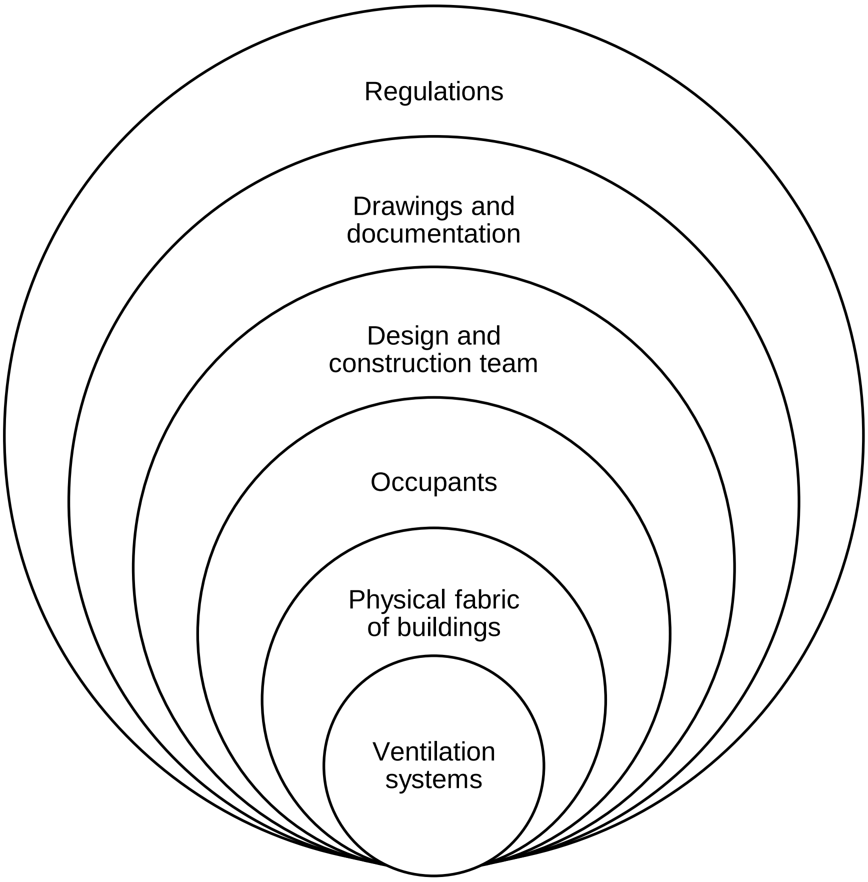

Figure 31: Socio-technical arrangement of each research case

As it was anticipated that it might not be feasible to meet everyone who was involved in the project, it was decided to prioritise key informants, who were identified before commencing with fieldwork. These included the architect, contractor and RSL. It was hoped that further participants would be identified along the way. This was possible in some cases, but certain

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[103] A discussion of the physical arrangement of each development is presented in Chapter 5, while a detailed description of the three cases is included in Appendix C.

individuals proved challenging to identify, such as the various subcontractors who only worked on the project for short periods of time (e.g. ventilation installers, bricklayers, electrical contractors). After the first interview was conducted at each case, subsequent participants were contacted opportunistically, based on the first informant's suggestions. Some groups were found to be particularly resistant to recruitment (e.g. housing officers) and one was no longer in business (contractor at Case A).

Another strength of using case studies in research is that they can enable the effective gathering of multiple sources of evidence relating to a particular problem or topic, based on different types of data. The value of research designs which combine different techniques to gather data is advocated by Morgan (2007). A variety of sources were used to collect data for this study. These include design and construction documentation, resident interviews, design team interviews, RSL interviews, walk-throughs in residents' homes, photography, and POE reports (see next section). By collecting different types of data from different sources it was hoped to assemble a rich picture of the design and use of domestic ventilation technologies. This would be difficult to obtain without the use of cases as the volume of data associated with each individual may have been prohibitively large to allow for meaningful analysis.[104]

4.4. Research methods

4.4.1. Fieldwork

This section provides an overview of the different methods used to collect and analyse data, demonstrating that:

- A variety of appropriate methods were used to collect different types of data relating to the central research problems,
- A systematic and reflective approach was taken, with each step carefully documented (see 4.4.2),
- Best practice was adhered to so that the research is safe and ethical (see Appendix A.4: Research ethics).

The different methods used at each stage of the fieldwork are documented in Table 20 and discussed below.

Table 20: Overview of empirical research methods

	Resident interview	Non-resident interview	Prompting activity	Resident walk-through	Photography	Document gathering

[104] For example, at each case study site several research participants (residents) were associated with just one design team, made up of RSLs, architects and contractors, and one set of design and construction documents.

Test interviews (January 2012)	Yes	No	Yes	Yes	No	No
Preliminary fieldwork (February - March 2012)	Yes	No	Yes	Yes	Yes	Yes
Main fieldwork (January - July 2013)	Yes	Yes	No	Yes	Yes	Yes

Interviews were a key method of data collection in this study. Hitchings (2012) argues that interviews are a particularly valuable method for researching routine practices. Table 21 presents a summary of the interviews which were conducted as part of the fieldwork.

Table 21: Schedule of interviews[105]

			Outside of case studies	**MEV (Case A)**	**MVHR (Case B)**	**PSV (Case C)**
Year 1	Test interviews	Residents	3 Residents			
	Preliminary fieldwork			**1 Resident** (Ali)	**1 Resident** (Betty)	**1 Resident** (Carla)
Year 2	Main fieldwork			**4 Residents** (Sabeen, Fara, Karen, Pamela)	**5 Residents** (Paul, Dan, Anthony, Steve Luke)	**3 Residents** (Sarah, Maria, Joy)
		Design and Construction Team		**1 Architect** (Christopher)	**2 Architects**[106] (Mark, Dominic)	**1 Architect** (Helen)
					1 Contractor (Stuart)	**1 Contractor** (Martin)
		Housing Association		**1 Sustainability Officer** (Yvonne)	**1 Housing Officer** (Janet)	**1 Technical Manager** (Michael)
				1 Sustainability Manager (Eddie)	**1 Project Manager** (Brian)	**1 Business Manager** (Douglas)

[105] Shaded cells indicate interviews which were coded and analysed.
[106] A different architectural practice was responsible for planning and another for the construction stage; therefore, one architect from each practice was interviewed.

		Misc.		**1 POE Consultant** (Richard)[107]		

Test interviews

Rationale

The interview guide and administration technique were pre-tested by conducting three interviews with participants who were known to the researcher. The aim of the test interviews was to resolve the mechanics of the interview as a research instrument and to develop and fine-tune the individual components of the interview (Sarantakos, 2005). It was also an opportunity for the researcher to develop their interview skills as this was their first experience of qualitative social research. For that reason it was felt acceptable to work with participants living in traditional, naturally ventilated homes.

The aim of these interviews was to:

- Practice interview technique,
- Test duration of interviews,
- Assess whether questions were delivered in a way the participant could understand,
- Test engagement with, and effectiveness of, the prompting activity (see below).

The selection of discussion topics was guided by the literature review and included 'window and door opening', 'condensation and mould', 'occupancy and routine', 'health and indoor air quality (IAQ)', 'utility bills', 'thermal comfort' and 'sustainability'. These topics were framed around the broad themes of 'past experience', 'context', 'beliefs' and 'knowledge'.[108]

Prompting task

A short activity was designed to be included at the end of each interview, to act as a prompt, and to encourage residents to talk about certain words and phrases relating to domestic ventilation. The aim of this was to explore participants' knowledge of certain issues, without doing a test. This approach reflects how the initial aims of the project were grounded in a more individualistic approach. However, after the preliminary fieldwork was conducted the direction of the research shifted towards a more collective and social exploration of ventilation practices. Therefore, this task was not used during the main fieldwork phase.

A brief description of the prompting activity is presented in Appendix A1. Each test interview lasted between 30 minutes and 1 hours, and was recorded and transcribed verbatim. The

[107] Also a ventilation expert.

[108] See Appendix A.3: Example interview schedules.

transcripts were coded using an inductive approach (see 4.4.2). A list of codes generated during this process is presented in Appendix B, Table 23.

Preliminary fieldwork

Rationale

Preliminary fieldwork, comprising three in-depth resident interviews, was carried out in spring 2012. An interview was conducted with one resident at each case study site, followed by a walkthrough of the dwelling, during which time photographs were taken to capture the different components of the ventilation system and their locations within the dwelling.

The aim of the interviews was to:

- Collect preliminary qualitative data relating to domestic ventilation practices,
- Test duration of transcription time, so as to estimate feasibility of repeating the process on a larger sample,
- Develop qualitative analysis skills. The process of transcribing the data enabled the researcher to appraise and evaluate their interview technique, as well as to learn the conventions of transcript notation,
- Test feasibility of analysing different types of data,
- Provide preliminary insights into the research phenomenon with a view to informing the direction of further fieldwork.

Practicalities

Participants were selected and approached by their housing officer who then helped arrange the interview. An interview schedule was developed, which comprised a list of open-ended questions which could be used as prompts for the discussion, and was based on the topics and themes used in the initial test interviews. Some additional questions were added for each interview, relating to the specific ventilation strategy at that case. The researcher sought to maintain a balance between directly asking residents to explain their ventilation technology and talking about particular incidents and events. Although the former was useful, it appeared that residents in particular found it easier to discuss memorable incidents rather than routine interactions with technological artefacts.

An example of an interview schedule is presented in Appendix A.3: Example interview schedules (Figure 63). The actual interviews were conducted flexibly, so that questions were omitted or added as appropriate. A series of prompts was used during each interview, based on the initial activity developed for the test interviews (see Appendix A.1: Interview prompts). Each interview lasted between 1 and 1.5 hours, and was recorded and transcribed verbatim. These data were analysed twice: first during this preliminary stage of the research and a second time following the completion of further fieldwork in 2013 (see 4.4.2 Interpretation and analysis).

Main fieldwork: resident interviews

Resident interviews

Following the analysis of the three preliminary interviews, a second round of resident interviews was planned for the second year fieldwork. The aim of these interviews was to:

- Provide a larger data set to cover a wider range of resident experiences and circumstances,
- Evaluate whether preliminary observations and analysis findings could be also applied to other residents and households,
- Follow up on issues raised during the first round of interviews, (in particular handover procedures, instruction manuals and interaction with design team and RSLs.

Recruitment

At Case A, residents were being recruited for the RSLs 'Green Doctor'[109] scheme at the same time as this research was being conducted. As the RSL offered each household gift vouchers to take part in the Green Doctor scheme, they suggested that the best way to recruit participants for the interviews was to offer them the same reward as an incentive.[110] The RSL then helped schedule further interviews with participants. Four participates were recruited this way.

At Case B, residents were contacted directly by the researcher (by post and telephone). Recruitment was fairly straightforward as participation in POE work was part of the tenants' lease agreement and most residents appeared willing to take part in interviews.[111] Five participants were recruited this way.

At Case C, the housing officer was contacted to ask for help arranging an introduction to residents. Letters were sent out to each household but it was not possible to obtain names or phone numbers to follow up the request, owing to data protection protocol. No residents responded to the request letters.[112] Following this, homes were visited in person (with a colleague) to ask for help. No financial incentive was offered. Three participates were recruited this way.

All interviews were guided by the same schedule as the preliminary interviews. The conversations lasted between 25 minutes and 1.5 hours and were transcribed verbatim.

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[109] http://www.groundwork.org.uk/Sites/south/Website/housing-associations-south (accessed 10/06/15). Green Doctor is a service offered by the charity 'Groundwork' to housing associations.
[110] A £30 'Love2shop' voucher.
[111] Simultaneous to conducting the fieldwork, the researcher was involved in a UCL POE project at Case B, which aided the recruitment process.
[112] As this scheme has been the subject of a student-led POE project a few years earlier it was suspected that residents may be reluctant to participate in more research work.

Main fieldwork: Non-resident interviews

Rationale

After completing the preliminary fieldwork the research scope was expanded to members of the design team and the RSL (see also 4.3.2, 'Practicalities of working with cases'). A difference between the residents' explanation of how their ventilation system worked and that described by the architect in the project documentation was noticed whilst analysing the preliminary interview data. For example, reproduced below is a description of the ventilation system extracted from at POE report, compared with the residents' version:

> *'Mechanical extract ventilation (MEV) with continuous extract from bathroom and kitchen, with humidity controlled wall inlets. The bathroom extract grilles include PIR [passive infrared] detectors to boost extract when rooms are occupied, and there is a boost switch to increase air flow when cooking.' [Case A document]* [113]
>
> *'Air system they have in place which circulates the air around the house, which is in the attic [….] they're actually being fed by a system upstairs in the attic (…) from what I understand they're pulling the air in and pushing it around the house' [Ali]*

This indicated that there was scope for further investigation of differences between designers' understanding of a system and their expectations of how it would be used, and that of the residents.

Schweber and Leiringer (2012) point out that *'51% of the non-technical contributions to CR* [construction research] *journals such as BRI* [Building Research and Information]*, BSERT* [Building Services Engineering Research & Technology] *and Construction, Management and Economics (CME) are about occupants, while only 21% of the non-technical articles in the CR set examine the construction process (design, procurement, construction, maintenance and demolition combined)'* (p.487).[114] Moreover, research around the uptake of new technologies tends to assume *'that the technology is purposefully chosen by the end user, and that this user is already in the home before the arrival of the new technology'* (Behar and Chiu, 2013, p.2395).[115] This would only be possible with domestic ventilation technologies in new-build, self-build or retrofit situations and did not happen at any of the cases explored herein; instead, the systems were chosen, specified and purchased by other 'intermediary owners' of the systems. Therefore, it was deemed necessary to include a wider range of actors in the study to understand why certain systems were chosen and how the final built configurations came about.

The aim of the non-resident interviews was to:

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[113] Reference anonymised for confidentiality purposes.
[114] Text in square brackets added by thesis author.
[115] Published paper based on analysis of preliminary fieldwork.

- Explore some of the differences between residents' and building designers' and managers' ideas about domestic ventilation,
- Investigate how the dwellings came to be designed in the way they were to provide context for the exploration of domestic practices,
- Understand some of the residents' experiences of interacting with architects and RSLs, (e.g. during handover), from the perspective of the architect and RSL.

Recruitment

Initial contact was made with key informants at the design teams and RSLs. For all three cases the architects were very willing to take part in an interview; they also suggested additional participants and provided contact details where possible (snowball sampling). This led to two contractors being contacted and subsequently interviewed.[116]

The first points of contact at the RSLs at Cases A and C were the housing managers. These were found to be somewhat reluctant to take part in interviews; for example, one housing manager (Case C) explained that she had only visited the site once during the previous year, to resolve a parking issue, so she did not feel she would have much to contribute. However, alternative contacts within the RSL were identified (online via websites and social media such as LinkedIn, as well as through colleagues) and several representatives from each case were successfully recruited for an interview. At Case B, the researcher was involved in a POE study taking place simultaneously, and was already acquainted with the housing officer, who agreed to be interviewed and suggested another colleague who was also interviewed.[117] Owing to the circumstances outlined above, the representatives of the RSLs who were interviewed do not all carry out the same role within their organisations; for example, interviews were conducted with members of the management and sustainability teams, a project manager, and the aforementioned housing officer (see Table 21, p.110).

Interview schedule

A schedule was prepared for each interview comprising a list of open-ended questions which could be used as prompts for the discussion. The schedules were not intended to be exhaustive, but rather provide a range of topics and conversation points to guide the conversation. The same broad topics were covered in each interview, based on the chronological design process, as follows:

- Design of scheme
- Construction phase

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[116] The third was no longer in business according to the architect and could not be contacted.
[117] The issue of being an 'insider' in this case and the effect this may have had on the process and outcomes of the research is discussed in section 8.5. For example, unanticipated events during the fieldwork phase constrained the collection of additional data.

- Commissioning and handover
- Buildings in use

Additional questions were asked about each participants' personal experience of domestic ventilation and their views on sustainability issues. An example of a non-resident interview schedule is reproduced in Appendix A.3: Example interview schedules (Figure 64). All interviews were recorded and transcribed verbatim, and lasted between 45 minutes and 1.5 hours.

Walk-throughs, photography, document gathering and memo writing

Walk-throughs

A walkthrough survey of the dwelling was conducted with each of the residents, either during or immediately after the interview. Initially, the walkthrough was to take place at the end of the interview, but it was later decided that the walkthrough should take place at the most natural point during the interview, often when invited by the resident to go and look at something together:

> *'CB: So tell me a bit more about the ventilation system; I'm interested in it.*
>
> *Ali: I'll show you it. Shall we go around?'*

During the walkthroughs, residents were asked to point out and demonstrate how they used each of the ventilation system components, (e.g. windows, vents, boosters). Walking through the home together acted as a prompt for residents, reminding them of details and events. Simultaneously, the dwelling was visually checked for signs of inadequate ventilation, such as mould or condensation as well as for objects and clues related to practices which had not previously been discussed (e.g. electric fans on bedside tables, see Figure 43). In several instances it was not possible to enter a certain room because of a sleeping member of the family. Otherwise, all rooms were entered in each dwelling.

Photography

An important aspect of the resident interviews and walkthroughs was the use of photography as a way of documenting visual evidence about the case studies. By taking photographs of the position of windows and curtains it was possible to obtain a snapshot of the physical arrangement of the home at the time of the interview. Photos were also taken of boiler and thermostat settings, which could later be referred to when reviewing the residents' comments about the heating. Comparison of window positions (e.g. whether they were open or closed), heating settings and local weather on the day of the interview provided insight into the use of windows under various weather conditions. The configuration of the ventilation systems, and any pieces of furniture in their proximity, were also recorded through photography. Finally, photographs were taken to record extracts from documents which were presented by the residents during the interview, such as operation and maintenance manuals. During interviews with non-residents, photography was used to a much lesser extent, usually with the purpose of recording the names of documents which could later be requested via email or found online.

Document gathering

Additional data were gathered in the form of various pieces of documentation, relating to each of the three cases. Planning and construction drawings, schedules, design and access statements, specifications and project briefs were provided by architects. These were redrawn to produce the layout diagrams presented in section 5.1.

POE reports were also obtained for each of the projects, one from the architect (Case A), the second from a previous student's MSc dissertation (Case C), and the third from the organisation who were carrying out the evaluation work (Case B). Documents were collected at each stage of the fieldwork as they became available or known to the researcher. This kind of supporting evidence was invaluable during the analysis as it facilitated a more detailed description and analysis of each of the cases. For example, the orientation of particular rooms was deduced from the site drawings.

Memo writing

A handwritten memo was recorded immediately after each interview. The use of memos is advised by Bazeley (2007) as a way of *'recording additional observations, reflections* […..] [and] *thoughts about the meaning or significance of things that were said'* during fieldwork (p.55). In this project, memos were used as a way of recording initial impressions of how the interview went and to reflect on what key ideas were emerging. Memos were also used to make a note of conversations which took place outside of the recording. Furthermore, the memo was used to record things which were observed but may not have been picked up in the audio recording, such as facial expressions, body language or smells. Each memo was later typed up and recorded in the NVivo project file (See section 4.4.2, below). Each memo was treated as any other piece of data during analysis and was coded. The memos written as part of this research are reproduced in Appendix B (p.249).

Ethics and data protection

This research was carried out in accordance with ethical and best practice guidance and the project was registered with the UCL Data Protection Officer (Z6364106/2012/01/33). A summary of the ethical considerations which relate to this work is included in Appendix A.4: Research ethics.

4.4.2. Interpretation and analysis

Analysis began as soon as data were collected and continued throughout the thesis writing. The different elements of this process are described below. Progression through the elements was not linear; instead an iterative strategy was adopted in the production of this thesis.

Use of computer aided qualitative data analysis

NVivo 10 (QSR International, 2012) software was used as a tool to organise and manage data and with which to conduct analysis. Computer aided qualitative data analysis (CAQDA) software is particularly useful for working with large volumes of data which need to be quickly retrieved and cross-referenced, a process which can be laborious and inaccurate when carried out manually (Lewins, 2008). By using CAQDA, it was also straightforward to add new data to the existing file, so that preliminary interview data could be integrated with the main fieldwork, forming one complete dataset. Furthermore, CAQDA allows different types of data (e.g. transcripts, memos photos and documents) to be stored in the same file and analysed as a whole.

The recorded audio data were transcribed verbatim[118] into an MS Word file and then transferred to the NVivo project.[119] An extract of transcribed text from one interview is presented in Appendix B.3: Example of transcribed data (Figure 65). All photos and documents were also labelled and a thumbnail stored in the NVivo project file.

Reading and reflecting on data

A detailed reading of each transcript was made to begin the analysis process. During this time the researcher made notes, extracted quotes, referred to the literature, and noted down emerging themes as a possible coding structure. The use of memos was critical during the main fieldwork analysis. Initial interview memos were read before coding started and a second memo was started to summarise the key points and to record ideas and insights emerging while coding. The memos written while analysing the interviews are presented in Appendix B.2: Analysis memos.

Categorising and coding

Strauss and Corbin (1990) define coding as '*extracting concepts from raw data and developing them in terms of their properties and dimensions'* p.159. In this thesis, coding refers to the process of 'categorising' and 'unitising' qualitative data, as described in Saunders et al. (2009, p.492). The process involves assigning 'codes' or labels to segments of data (textual or otherwise), which can then be retrieved and reordered either manually or using queries.

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[118] Express Scribe software was used to slow down the audio recordings to aid transcription.

[119] Initially the preliminary interview transcripts were analysed without using CAQDA. The transcripts were first read and annotated. Then key quotes were cut and pasted into a separate file under thematic headings with reflections and ideas noted in the relevant section. This new document was then imported into NVivo for coding and analysis. Following the second round of data collection this process was omitted. Transcripts were directly imported into NVivo where reading, reflecting and coding took place concurrently. The first approach was deemed cumbersome and also resulted in interesting data being missed as it was not always 'spotted' the first time round and was therefore lost from the dataset.

After the initial reading, each transcript was reviewed a second time and systematically coded according to ideas, concepts or themes which emerged from the text. In the preliminary fieldwork interviews, an inductive approach was taken whereby each line of data was carefully explored for relevant meanings and categories (see, Appendix B.2: Analysis memos, Table 24). When using an inductive approach, data are condensed, grouped and then reconstructed into a narrative (Saunders et al., 2009).

Coding of data collected during the main fieldwork period was carried out using both an inductive and deductive approach. In deductive coding the categories of data and analysis codes are developed from the theory and are therefore assigned according to a more structured framework. The reason for this development is that certain themes were developed during the analysis of the preliminary data which led to the decision to adopt social practice theory as a theoretical framework for the research. The importance of daily routines, past experiences and the use of space in people's experience of ventilation (see codes highlighted in bold in Appendix B, Table 23), prompted the development of a priori categories, which were then used when coding the main dataset. The deductive (a priori) and inductive codes used and generated whilst coding the main dataset are presented in Appendix B, Table 26 and Table 27.

At this stage the preliminary interviews were also re-coded according to the new set of codes.[120] As well as coding the interview transcripts, each photograph and all documents were also coded using the same codes.[121] Each photograph or document was also linked to the exact place in the transcript where it was taken or introduced so that all types of data could be explored simultaneously. Coding is an iterative process; new codes were added where relevant and others removed, rearranged, combined or split as the analysis progressed and deepened. During this stage the research questions remained fluid and evolved into their final form.

Although the analysis was primarily qualitative, the number of references and sources (e.g. transcript, photo, document) assigned to each code gave a useful indication of recurring themes and areas of concern or interest. A list of the number of sources where a code was assigned and the total number of references within a particular code was generated regularly to see which topics were discussed most often and which well less frequently visited. An extract of one such list is reproduced in Appendix B, Figure 67 (p. 282). As the analysis developed certain codes became more prominent (e.g. 'staying warm' and 'staying cool') and then formed the basis for more detailed analysis around ventilation practices relating to thermal comfort.

Reading, memo writing and coding formed a significant part of the research process. In addition, several of the features of NVivo were exploited to aid data retrieval and to help generate deeper insight while writing commenced. For example, framework matrices and sketch

[120] An example of a coded portion of text is presented in Appendix B, Table 25.
[121] An example of a coded photo is presented in Appendix B, Figure 66.

models were used to visualise and organise the relationships between certain codes.[122] This data analysis method is aligned with the constructivist-interpretivist research paradigm, where knowledge is constructed, first by the participants as they recount their experiences, and secondly by the researcher as s/he seeks to reconstruct the data in a way that '*makes sense'* and provides insight about the phenomenon being investigated, based on the adopted theoretical framework (Strauss and Corbin, 1990, p.12).

4.5. Summary

This chapter has positioned the thesis as an interdisciplinary endeavour carried out within the interpretive research paradigm. Section 4.1 argued that research which is located between disciplines and which is exploratory in nature is required, to construct a more comprehensive understanding of domestic ventilation practices in LEH. Section 4.2 explained how a qualitative methodology was selected as a natural partner to a study of social practices and physical arrangements. Taking an interpretive position does not mean rejecting the importance of the physical fabric of dwellings; the aim of this research is to broaden the investigation by taking a more holistic view, where social and physical entities are treated as equal components of a socio-technical system arrangement. Hopefully this thesis will also contribute in a small way towards redressing the dominance of positivism in the field of energy demand research by providing complimentary evidence from a different perspective.

In section 4.3, the use of case studies was presented as an appropriate strategy with which to undertake an exploratory research project aimed at answering qualitative questions about *how* people interact with different domestic ventilation technologies. Finally the social research methods used to collect and interpret data were introduced and discussed in section 4.4. The use of interviews, photography, walk-throughs and document analysis is considered appropriate to explore the research problem from a variety of perspectives. By using multiple sources of data the study presents an authentic and credible exploration of how people are adapting to living with WHV.

The next three chapters present the analysis and findings of this research. Chapter 5 considers the physical arrangement of homes with WHV, Chapter 6 discusses the bundles of everyday activities and artefacts which make up ventilation practices, and Chapter 7 introduces the idea of 'disruptions' as potential moments of change in the evolution of ventilation practices.

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[122] An example of output from this kind of analysis is presented in Appendix B, Figure 69, Figure 69, and Table 29.

Chapter 5: The physical arrangement of homes with whole house ventilation

This chapter has two key aims: Firstly, to investigate how the design intent around the construction of homes with whole house ventilation (WHV) systems is materialised in a physical arrangement, which can prefigure (constrain and enable) residents' ventilation practices (Research Question 1). Secondly, to explore how modifications to the arrangement of physical entities, made by residents as they occupy their homes, prevent them performing ventilation as the designers intended and anticipated (Research Question 2). The concept of arrangements is borrowed from Schatzki (2002), to describe the physical configuration of the homes and their ventilation systems, which, together with social practices, forms bundles of interconnected activities and entities. The analysis is carried out with reference to the three case studies introduced in the previous chapter.

Section 5.1 presents a brief description of each of the cases which are then discussed in relation to their design, construction and inhabitation in the following sections. Section 5.2 discusses how when the ventilation strategy was not considered at the outset of the project it became 'lost' within a fragmented design team, whereas selecting the ventilation strategy early on in the design process enabled it to be integrated more fully into the design of the homes. Section 5.3 is concerned with understanding how in one of the cases, the design intent to combine a 'fabric first'[123] approach with more holistic sustainability ambitions has been materialised into arrangements which are challenging for the residents to ventilate and prone to overheating. Finally, section 5.4 considers how residents' inhabitation and furnishing of their homes can challenge and conflict with certain components of the ventilation system, potentially constraining the ventilation which takes place within them.

5.1. The three cases

This section presents an introduction to the three cases which were investigated in the research. A brief summary is followed by a description of each ventilation system and strategy.[124]

5.1.1. Case A: Mechanical Extract Ventilation in Prototype Sustainable Housing

Summary

This development comprises 14 terraced and semi-detached houses, which were commissioned in 2002 and completed in 2005 by a small, independent housing association (a

[123] See Glossary.
[124] A detailed description of each of the three cases, and a summary of the analysis which underpins this chapter, is included in Appendix C, The Three Case Studies.

registered social landlord (RSL)) in the south-east of England. The two-storey, two, three and four bedroom houses are spread across three terraces on the site (Figure 32). This was the first of three housing schemes commissioned by the RSL, and was intended to inform the development of a replicable model of sustainable, low-carbon housing. The RSL have a strong environmental agenda, strive to make sustainability *'the core of the organisation's business'* (Anon., 2008, p.5), and have won several awards for their sustainable approach to housing.

Figure 32: Case A site plan showing the five visited homes (scale 1:750)

Ventilation system and strategy

The dwellings are fitted with mechanical extract ventilation (MEV) to meet fresh air requirements. During summer, additional ventilation may be required to prevent overheating; windows are present in all rooms and can be opened for this purpose. Windows are not part of the wintertime background ventilation strategy. A central air-handling unit (Aerco) is located in the loft, connected to ceiling vents in the wet areas via ductwork. The loft is accessed from one of the bedroom storage mezzanines (see Figure 73 and Figure 74 in Appendix, p.288). The MEV continuously extracts at a low speed, and passive infrared detectors in the bathrooms and a boost switch in the kitchen serve to increase airflow to a higher rate, at times when greater concentrations of pollutants are being produced (Figure 75, Figure 76, p.289). Regular maintenance is required to remove dust and grease from the fans, grilles and filters (EST, 2006). Humidity controlled wall inlets in the habitable rooms allow in fresh air from outside. These are all located on external walls, behind a rainscreen cladding (Figure 77, p.290).

A typical layout is illustrated below, showing the location of the key ventilation components (Figure 33).

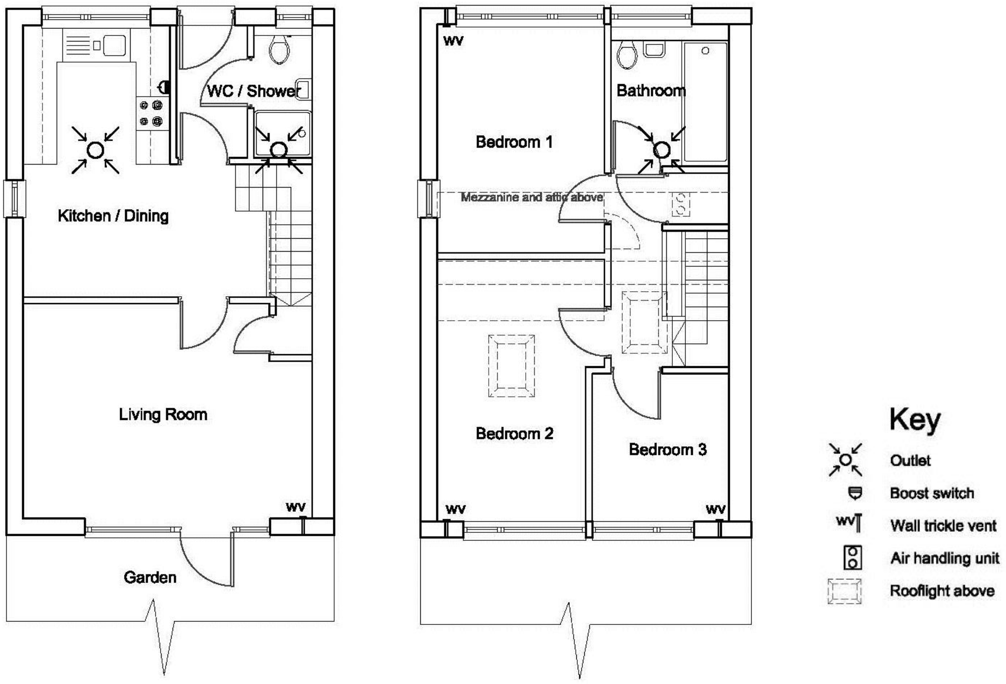

Figure 33: Typical 3-bed unit at Case A (scale 1:150, ground floor left, first floor right, orientation varies across site (see Figure 32))

5.1.2. Case B: Mechanical Ventilation with Heat Recovery at a Large Scale Regeneration Project

Summary

This case study comprises two apartment blocks, located on a much larger regeneration site in the South of England. The regeneration project is being developed under a consortium which includes a major national contractor and housebuilder, the local council and a local RSL, with investment from central government. The scheme comprises over 600 new homes, a large supermarket, a café and smaller retail units (Figure 118, p.310). The two blocks are each three storeys tall and contain 12 flats. Although they appear nearly identical in appearance they are actually mirrored in plan. One of the blocks is managed by the local RSL (Block 1) whereas the other contains flats available for shared-ownership (Block 2). Blocks 1 and 2 were part of Phase 1 (of 4) and were completed in 2011. Construction of later phases was still underway while fieldwork was conducted; the whole development is expected to be complete in 2017.

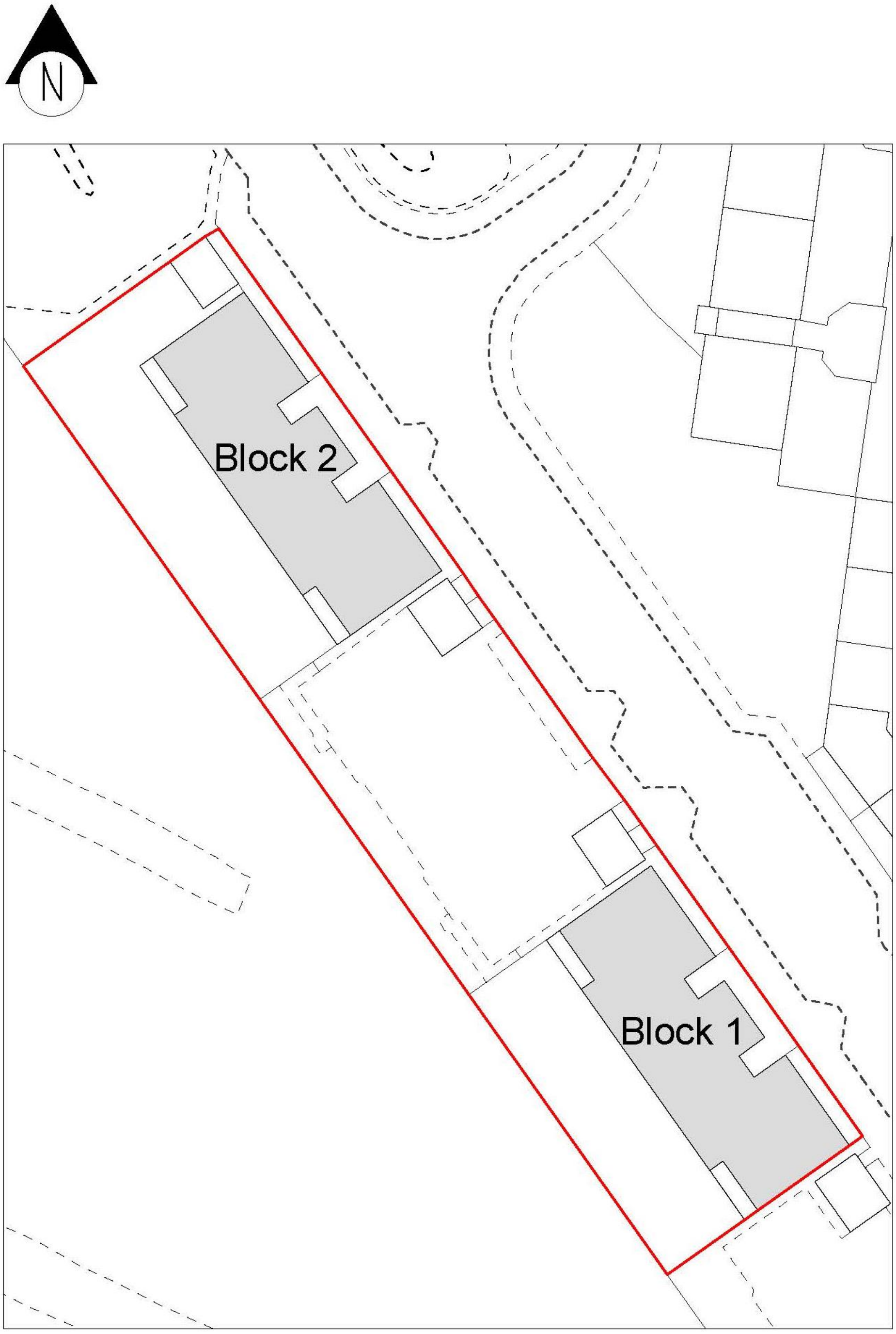

Figure 34: Case B site plan showing Blocks 1 and 2 (scale 1:750)

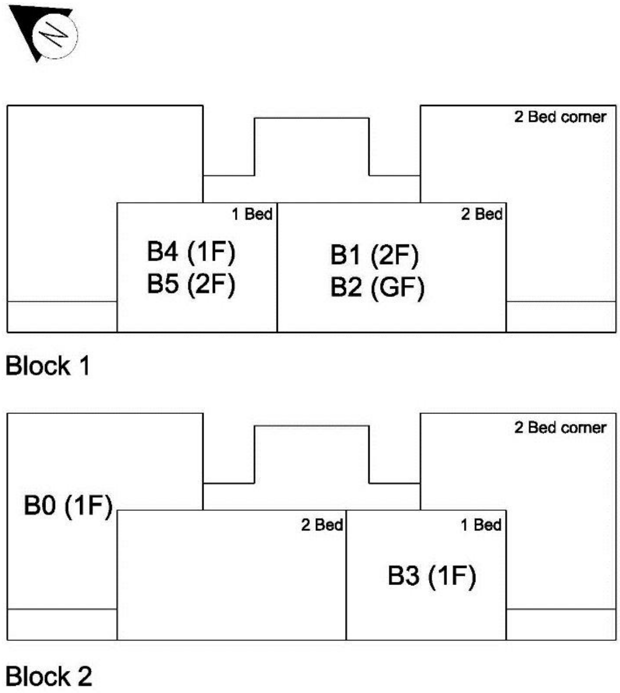

Figure 35: Diagram showing location of participants' homes at Case B (scale 1:400)

Ventilation system and strategy

The Ventilation strategy at this case study utilizes mechanical ventilation with heat recovery (MVHR). Each flat has its own MVHR unit (Titon HRV1 Q+), located in a cupboard in the hallway. Warm, vitiated air is extracted from wet areas (kitchen and bathroom) via vents, which are connected to a central unit via ductwork which runs within the suspended ceiling cavity (ground and first floor flats) and inside the ventilated roof space (second floor flats). The air passes through a heat exchanger which recovers heat from the stale air and uses it to preheat incoming fresh air from outside; fresh air is taken in via wall mounted louvres on the external elevation. This air is then distributed to the habitable rooms via a series of ducts and vents. During the summer, additional ventilation may be required to prevent overheating; windows can be opened for this purpose. Windows are not part of the wintertime background ventilation strategy.

In each flat there is a boost button in the kitchen. This can be pressed to increase the speed of fan at times when increased levels of pollutants are being generated. For example, it may be used when cooking or showering. The boost button is on a timer so that it stays on for approximately 15 minutes after being pressed, and then switches off automatically. There is no summer bypass mode in this installation.[125]

[125] Summer bypass, a recirculating cooker hood and a three-position switch for varying speed of fan were all included in the specification documents, but were not materialised in the final constructed scheme, for unknown reasons.

The systems were commissioned after installation and the initial results showed that the systems were performing according to design intent. However, later spot checks by the POE consultants revealed lower than expected flow rates and unbalanced systems (see Appendix C: The Three Case Studies).

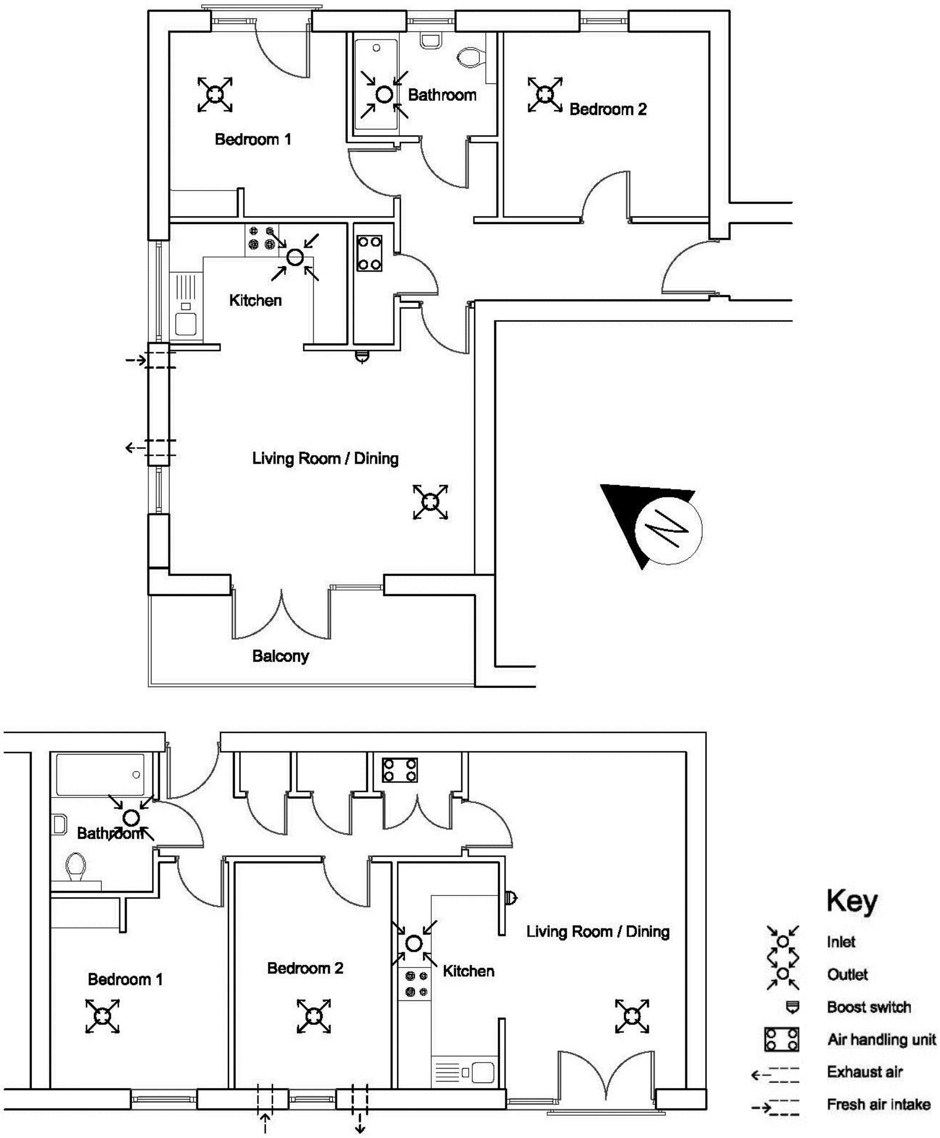

Figure 36: Typical 2-bed corner unit (above) and mid-block unit (below) at Case B (scale 1:150)

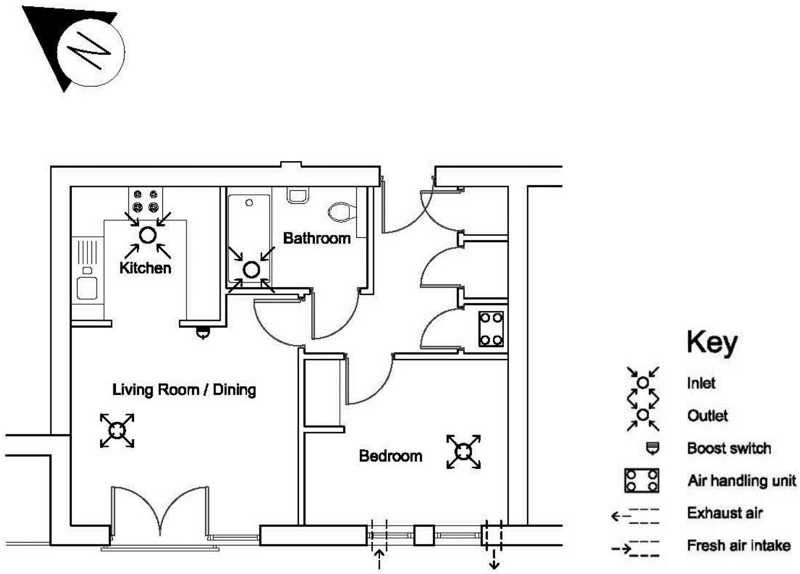

Figure 37: Typical 1-bed unit at Case B (scale 1:150)

5.1.3. Case C: Passive Stack Ventilation at an Urban Terrace

Summary

This case study comprises a development of nine, two and three storey terraced houses on a tight site at an urban location. The scheme was commissioned by a large RSL (currently managing 36,000+ homes) and was completed in 2008. The project was conceived as an exemplar sustainable housing scheme by the RSL, who viewed the project as an opportunity to rebrand themselves as a *'green housing developer'* (Michael).The development is adjacent to a children's play area and a car park, which it shares with the Local Authority owned block of flats which it faces. The accommodation comprises nine houses (with two to four bedrooms), each with a private front and rear garden (Figure 38).

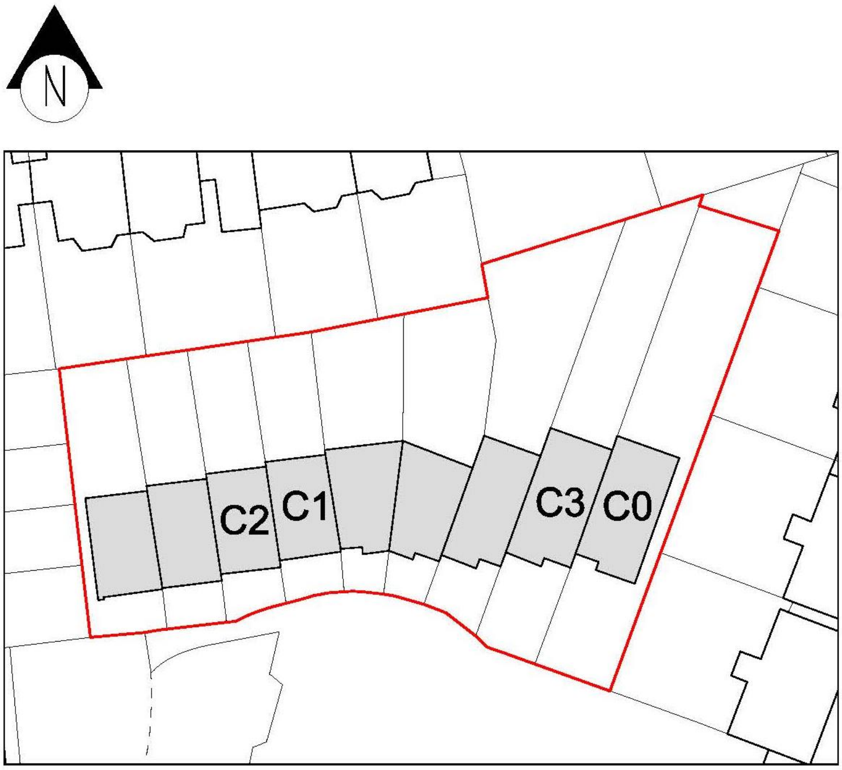

Figure 38: Site plan showing which homes were visited (scale 1:750)

Ventilation system and strategy

Fresh air is provided using passive stack ventilation (PSV). During the summer, additional ventilation may be required to prevent overheating; openable windows are provided in each room, except the first floor bathroom and downstairs utility room. Windows are not part of the wintertime background ventilation strategy.

The main components of PSV are ceiling or wall mounted extract grills, which are connected to roof terminals via vertical, or near-vertical, ductwork (Figure 162, p.340). The extracts are located in all wet areas, which in these dwellings include bathrooms, kitchens and utility rooms.[126] Fresh air is brought into the house through trickle vents, which are incorporated into the window frame in all habitable rooms (bedrooms and living areas) (Figure 166, p.342). The are no fans or electrical components in the system as it relies fully on the buoyancy effect created by the pressure difference between warmer stale air and cooler fresh air to drive the movement of air through the spaces. A '*breathing wall'* construction detail, incorporating '*natural paints'* was designed for the external envelope to enable moisture to pass through and to avoid condensation (Anon., 2009).[127]

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[126] Utility rooms are found only in the larger houses.
[127] The terms in quotations are reproduced from a student dissertation undertaken in 2009 and based on the POE of the case study development. The author and title have been anonymised to protect the identity of the research participants but extracts can be provided upon request.

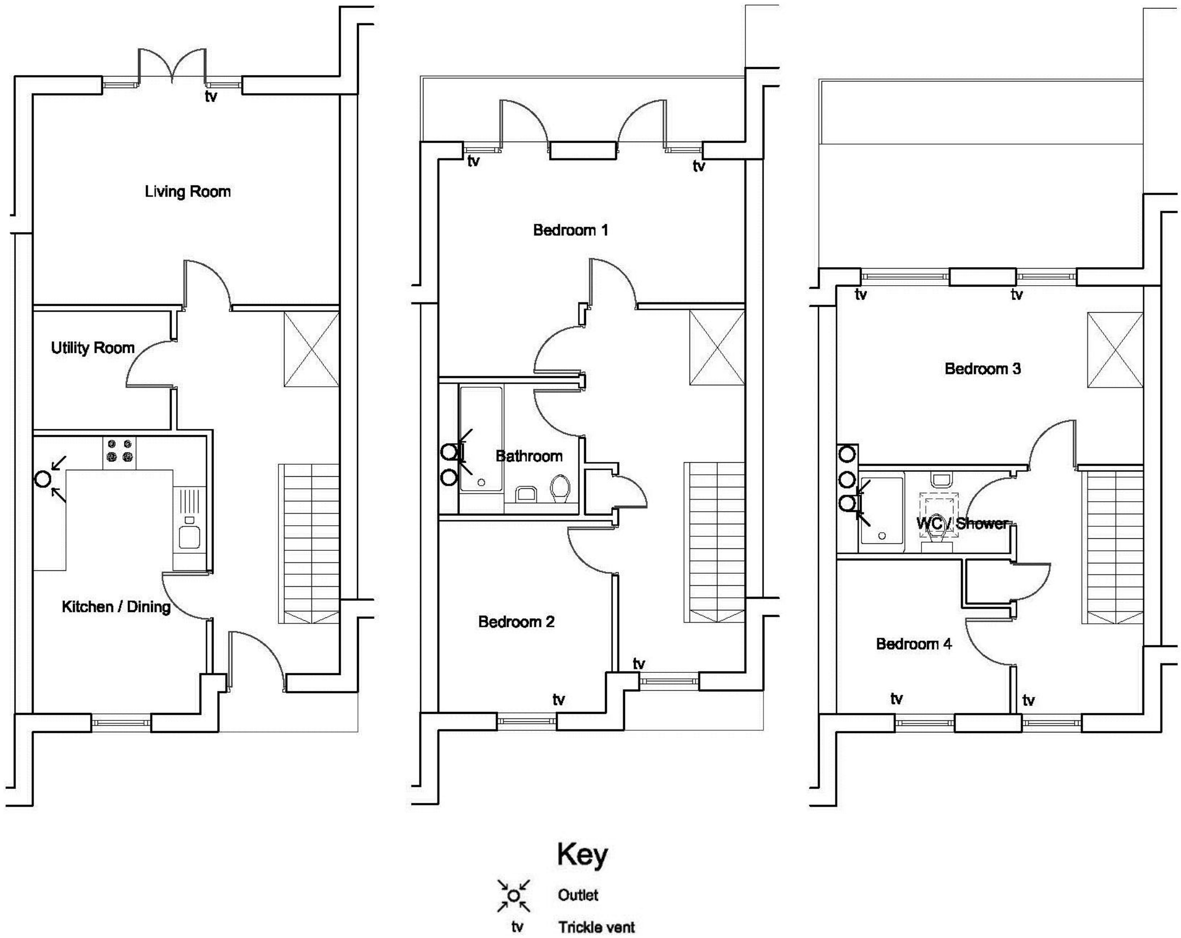

Figure 39: Typical 4-bed unit at Case C (scale 1:150, ground floor left, first floor centre, second floor right. Orientation of properties varies across site (see Figure 38))

5.1.4. Summary table

The three case studies are summarised below (Table 22). The table also shows the target and measured airtightness achieved at the three cases. This demonstrates how the level of ambition was greater at Cases A and C which had lower permeability targets despite being completed five and three years before Case B, respectively.

Table 22: Summary of three case studies

	Case A (MEV)	Case B (MVHR)	Case C (PSV)
Completion date	2005	2011	2008
Number of units	14 terraced and semi-detached houses	24 flats (phase 1 only)	9 terraced and semi-detached houses
Tenure	General needs (rental)	General needs (rental) and shared ownership	General needs (rental)
Airtightness target	1 $m^3/h.m^2$ @50Pa	4 $m^3/h.m^2$ @50Pa	2 $m^3/h.m^2$ @50Pa
Airtightness (measured)	Ranged from 2.96 $m^3/h.m^2$ @50Pa to 4.40 $m^3/h.m^2$ @50Pa	Ranged from 4.95 $m^3/h.m^2$ @50Pa to 5.95 $m^3/h.m^2$ @50Pa	Ranged from 2.3 $m^3/h.m^2$ @50Pa (mid terrace) to 3.6 $m^3/h.m^2$ @50Pa (end of terrace)
Measured gas consumption	70 $kWh/m^2/y$		41 - 146 $kWh/m^2/y$
Measured electricity consumption	42 $kWh/m^2/y$		20 - 36 $kWh/m^2/y$

5.2. Choosing a ventilation strategy

In this section, Case B (MVHR) is used to discuss how when the ventilation strategy was not considered at the outset of the project it became 'lost' within a fragmented design team. This is contrasted with Case C, where PSV was planned from the earliest stages of the design.

The housing development at Case B is part of an ongoing, large scale regeneration project where over 500 substandard homes were purchased under Compulsory Purchase Orders (CPO), and demolished to make way for new housing and retail facilities. All the buildings were initially designed to Code for Sustainable Homes 3 (CSH3), which the planning stage architect described as *'minimal ambition'* (Mark); in a project where the primary focus was on the regeneration of a historically neglected and deprived area, environmental sustainability was a much lower priority than at the other two cases. Towards the end of the planning stage, additional funding was obtained to increase the specification of one of the buildings (Block 2) to test the performance of the Fabric Energy Efficiency Standard (FEES).[128] This was achieved by doubling the thickness of the external wall insulation to 200 mm and by insulating all party walls between flats.

Two architectural practices were involved in the design of the buildings. While one team took the project through the initial planning stages, a different practice was appointed to prepare the detailed design and construction drawings. Furthermore, as this was a 'design and build'[129] project for a developer-contractor, neither architectural practice was involved in supervising the construction of the project on site, as this was overseen by the developer. This contrasts with the other two cases where a single architectural firm was responsible for the planning and detail design stages of the project, as well as for the selection of the ventilation strategy. This kind of separation between 'design' and 'delivery' architects is not uncommon in the UK architectural profession. However, an investigation into how the ventilation strategy was selected, designed, specified and installed reveals how a fragmented design team is not just a contractual arrangement, but that it has implications for how the ventilation system is arranged as part of the built physical fabric.

5.2.1. MVHR introduced after planning stage

Despite speaking to both lead architects, two representatives from the client and the contractor-developer, it still unclear exactly who chose the ventilation strategy and at what point in the design process this decision was made. However, it is evident that ventilation was not

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[128] The Fabric Energy Efficiency Standard (FEES) is the proposed maximum space heating and cooling energy demand for zero carbon homes. It was developed by the Zero Carbon Hub (ZCH) and is expressed in kWh/m^2/year, with a maximum value of 39 kWh/m^2/year for apartment blocks and mid-terrace homes and 46 kWh/m^2/year for end of terrace or detached homes (ZCH, 2015a).
[129] See Glossary.

considered by the architects at the outset of the project, but that it was something which was introduced later on, perhaps to comply with building regulations. This is demonstrated by the fact that the planning stage architect believed that the dwellings were naturally ventilated and, having never visited the site during or since construction (as *'that would be within the remit of the architects doing the working drawing stage if indeed they do at all'* (Mark)), was surprised to learn, during the interview, that MVHR had been installed. For this practice, ventilation design is not typically considered until after the planning stages of a project:

> *'There wasn't any thought that there'd be anything other than natural ventilation in order to comply with that strategy and therefore it was just a sort of standard build really as far as we were concerned.' (Mark)*

The architect went on to explain that '*the reality is that really at planning stage we would very rarely get into that sort of detail'* and that ventilation is '*not really something which has an impact on the design stage'*. This contrasts with the way the architect at Case C described the choice of ventilation; here the ventilation technology is considered at the start of the project and is much more tightly connected to the performance of the building fabric and it's airtightness:

> *'It was definitely going to be natural ventilation and sort of consistent with a kind of good level of it [….] At that point there was no question of using mechanical ventilation [….]. You would only have used mechanical ventilation if you were going the next step-- wouldn't ever have been any thought of doing anything different.' (Helen)*

At Case B, the architect who was in charge of preparing the construction package started working on the project after planning permission was granted. He explained that MVHR had already been chosen for the ventilation strategy before his involvement. This was a somewhat surprisingly statement given the aforementioned comments made by the planning architect. He also believed that MVHR was part of the developer's '*initial energy strategy [….] to try and get the SAP and the Code, for this particular site,'* without resorting to on site energy generation from renewable sources (Dominic).

> *'I think that was the most, from their point of view, a 'renewable' technology, they would stretch to because it's-- it was dealing with the ventilation, they didn't have to worry about trickle ventilation [….], it was doing quite a few jobs in one hit. You're getting better SAPs, better Code, better thermal performance, better airtightness'. (Dominic)*

If the ventilation was part of any initial energy strategy then it seems likely that that neither energy use nor ventilation were considered until after the planning stage of the project.

At this case, unlike at the two others, the contractor-developer was responsible for choosing the ventilation strategy. It was not possible to talk to the contractor, who had led the construction of this project, as they no longer worked at the organisation; however, the new '*technical coordinator'* for the regeneration project explained that '*with Code, the way forward was to use an MVHR system'* although he admitted that the decision was made *'long before my time'* as blocks 1 and 2 were '*were pretty much ready to put the roof on'* when he joined the team

(Stuart). The contractor confirmed the architect's hunch that MVHR was *'one of the design technologies that was there that was perceived as being the best solution in order to achieve those Code requirements with a fabric first, rather than renewables'*. MVHR was chosen as a way of achieving a certain compliance target using an *'envelope solution'* (Dominic) and without recourse to renewable technologies, which would require *'ongoing maintenance' (Dominic)*.

Regarding the actual choice of system and model, the contractor described how, as a large client, they negotiated '*group deals'* with suppliers, and that the specified manufacturer was *'found to be one of the more efficient or one of the more cost effective solutions of the time to fulfil that or achieve that Code 3'*. On the other hand, the project manager at the RSL suggests that the architect would usually lead the design team in choosing a ventilation strategy, by advising which is most suitable *'to hit the Code'* (Brian).

Although it has not been possible to identify the individual who was responsible for choosing the ventilation strategy, the discussion above demonstrates how, at Case B, the selection and specification of ventilation was very much compliance and cost led, and less closely connected to environmental design or performance targets than at the other two cases. The importance of achieving compliance at lowest cost, at this project, is exemplified in the following comment made by the housing officer about the choice of ventilation system:

> *'I do know we get points for eco, being eco-friendly and secured by design, so I'm assuming we get points and points means lots of money so that's the only reason I can think of. I don't know if it's right.' (Janet)*

5.2.2. PSV considered from the outset

The problem with choosing the ventilation strategy at a later stage in the design is that the range of possible systems reduces as certain options are no longer feasible. By the time MVHR was chosen at Case B, it may well have been the most appropriate strategy to meet the various requirements of the project. For example, PSV needs to be designed into the building '*from the beginning'* to allow for the arrangement of unobstructed *'vertical runs'* though the building fabric (Helen).[130]

At Case C, the decision to use PSV was made '*very early*' and came *'very much from the architects'* (Martin), where one of the directors had installed the same technology in her own home. The contractor explained how with PSV it was necessary to think about *'air flows through the building* [….] *at the time of your actually designing the building'* (Martin). This contractor admitted that he rarely works with PSV on other projects because *'the design expertise isn't there'* and because mechanical and electrical engineers '*tend to like kind of nice shiny bits of kit and things*'. Furthermore, because contractors are typically appointed post-planning, he finds

[130] Refer to description of 'System 2' in section 2.1.5 for duct requirements.

that, by the time they are '*involved in the buildings, […] it's too far designed to actually stick in a [PSV] system'* (Martin).

However, at this case, the contractor was involved from the very start of the project. After being impressed by a sustainable housing scheme developed by the local council, the RSL '*decided to take the whole team'*, including the architect and contractor, to work together on this development (Martin). This approach, described by the architect as '*incredibly enlightened'* and '*unique',* seems to have had a positive impact on the project as the contractor was able to contribute at early design meetings and the architect could continue visiting the project while it was on site, something which is not always possible (Helen). The architect attributes the success of the project to '*everybody working together*'. This cohesion would not have been possible at Case B, where the design team were fragmented across several organisations, with little interaction between them:

> *'As soon as you see something you go "why did he draw it like that?" and just-- the default but I think sometimes you've just got to sit there and go "okay, well what's he trying to achieve?" Because you very rare-- I think there's only been one occasion where I've been able to then go back and actually contact the planning architect and go "what is-- what are you going on about here because I haven't got a clue?"' (Dominic).*

At Case B, many of the main strategic decisions about the massing, layout and orientation of the buildings had already been made before ventilation was considered and MVHR selected. Even the locations of bin storage and bicycle parking were described in some detail in the design and access statement that accompanied the planning application; yet no reference was made to ventilation. Furthermore, because 'System 1' was assumed at the planning stage, space was not allocated in the flats for the MVHR fan unit,[131] although an indicative boiler location was marked in a storage cupboard.[132] However, changes to the design standards set by the developer, following reports of a fatality due to carbon monoxide poisoning, meant that the location of the boiler had to be repositioned, post-planning, so that all boilers were finally installed adjacent to external walls (Figure 40).

> *'That was one item where-- you know-- where we had to change-- introduce this cupboard on the external wall and then sort of build in a built in wardrobe to sort of make it then not look odd so that's where it sort of deviated from planning drawings.' (Dominic)*

[131] Typical dimensions required for a fan unit installation are 600 mm x 600 mm x 600 mm.
[132] This was shown to the researcher during the interview with Mark but was not marked on the planning set of drawings provided by him.

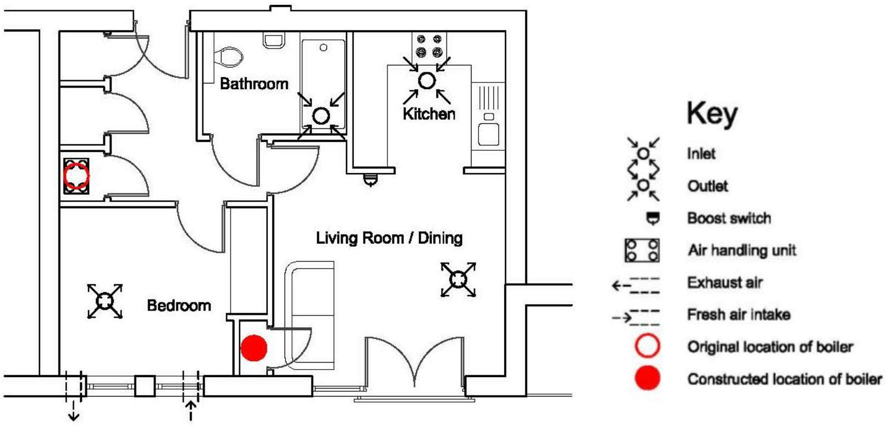

Figure 40: Diagram showing original and 'as built' location of boiler, with access door obstructed by resident's sofa (Case B)

The implication of this is that boilers are now located in a slightly awkward position in the living room and the space originally intended for the boilers is used to house the ventilation unit. In at least once dwelling, the way furniture has been arranged prevents the occupants from accessing the boiler, which they simply leave running all the time so that they do not have to move the sofa around (Figure 40).

> *'We've just been away for the weekend for four days and I didn't even bother switching it off then.' (Anthony)*

Even with MVHR, getting the layout right can be a challenge if the ventilation is not considered until after the building has been designed. The construction architect explained how *'there's quite a lot of co-ordination that needs to be involved'* to design and install MVHR in a small apartment, because they had to '*make sure that the routes don't clash with the steels'*. Because the apartments are single aspect and boilers had to be located adjacent to external walls, they found that they would rapidly '*run out of external wall where you can actually put the inlet'*, which had to be spaced at *'a certain distance of the flue outlet'.* This resulted in '*very limited space'* and '*quite a lot of torturous routes to get it all the way round'* (Dominic) which may have resulted in a poor quality installation and may explain the low ventilation rates discovered during later POE work (Appendix C The Three Case Studies).

This section has discussed how a fragmented design team constrained the choice of ventilation strategy to a single method of compliance, while a cohesive team approach enabled ventilation to be considered at an earlier stage, at a time when more options were available. The next section builds on this to consider how contradictions in the design ambition of a project are materialised into a ventilation strategy which does not necessarily align with the building fabric strategy.

5.3. How contradictory design ambition is materialised into a constrained ventilation strategy

In this section, Case A (MEV) is used to illustrate how, although the homes were designed with a certain ventilation and cooling strategy in mind, the realised physical arrangement is not always amenable to the intended use. In this case, the ambition to combine a fabric first approach with other sustainability interests has been materialised in a certain configuration of homes which is found to be challenging for the residents to ventilate and prone to overheating.

All three cases examined in this thesis share a fabric first approach, with a focus on an airtight and well insulated building envelope. The purpose of this strategy is to minimise heat losses during winter, thus reducing space heating demand as much as possible. Large areas of glazing (especially on south and western facades) are often employed with a fabric first approach, to maximise solar gain and reduce reliance on active heating systems, as well as to provide natural light so that less electrical lighting is needed. The fabric first maxim is commendable as it focuses on reducing energy demand, which may be one of the most cost-effective way of decarbonising the UK energy system (Boardman, 2007). However, Case A provides a clear example of how the resolution of an ambitious set of design targets can result in a physical arrangement which, although well considered, doesn't always align with the intended use.

5.3.1. Physical arrangement does not align with intended use

The design strategy for these homes places an *'emphasis on reducing energy demand by creating a well-insulated and airtight envelope'* (Christopher, Case A project case study). The intent was that the houses would be passively warmed during winter and also stay cool during summer, with minimum need for active heating or cooling.[133] However, according to one resident it's '*totally the opposite'* to what they were promised; Pamela experienced '*boiling hot'* temperatures during summer and felt *'very cold'* in winter. This view was shared by other residents at the homes, such as Ali, who complained of *'oppressively hot'* summertime conditions.

The architect explained how the design has addressed the potential for overheating, by including several rooflights in each of the homes to aid ventilative night cooling via the stack effect:

> *'You have a rooflight which is operating with the stack effect, so it's drawing air through the building and doing it at night. So what it's doing is pulling cool air through the building at night and then* ***you probably close the windows during the day****. You might leave the rooflight open but close the other windows-- because by--* ***in the morning it will be cool-ish and it will stay that way if the windows aren't open*** *and the insulation is*

[133] A conventional wet central heating system comprising a condensing boiler, thermostat and radiators is present at all three cases.

> *doing its job. And then the heat maybe builds up a bit during the day but then you vent it out at night.' (Christopher)*[134]

However, at these properties the construction system, comprising lightweight timber prefabricated panels, may be incompatible with the night cooling strategy. Ventilative night cooling can be an effective strategy for reducing peaks in internal temperatures by using a building's thermal mass to absorb heat during the hottest part of the day and releasing it at night when temperatures are lower. This technique benefits from heavyweight construction materials such as masonry or concrete to provide the thermal mass (Hacker et al., 2008). It also works best when windows are kept closed during the day and only opened once the external air starts to cool down in the evening.

Therefore, the use of timber as a construction material is surprising, as it is a lightweight material with a low thermal mass. However, the choice of timber is better understood as part of the overall sustainability strategy which called for a holistic approach to a number of issues, such as considering embodied as well as operational carbon emissions and the use of 'natural' materials. Although the overarching target for the project was to achieve CSH4, the client and architect agreed that other aspects of sustainably were equally important, which allowed them to go beyond the requirements of CSH4 in several areas. Furthermore, the project was conceived as the first stage in creating a prototype for environmentally, socially and economically sustainable housing that could be replicated by the RSL to expand their housing stock.[135] As all these goals had to be achieved *'within a conventional social housing budget'* (Christopher), the project was quite ambitious and experimental in scope. A suspended timber floor deck and a '*timber prefabricated substructure'* was proposed to decrease construction time and costs. This construction method tied in with the sustainable materials goals of the project which included '*zero PVC'* (Christopher), and '*natural building materials [….] to keep the house free of toxins'* (tenant information document).[136] Furthermore, the construction materials also aligned with the personal interests of the architect:

> *'I've always been interested in timber as a building material so I tended to do quite a lot of things in timber.' (Christopher)*

The choice of ventilation strategy also reflects the past experience of the architect. As well as aspiring to *'to go beyond the standard building regs solution'* (background ventilators and intermittent extract fans (System 1)), the specified system was one the architect was accustomed to living with, in his own home (MEV (System 3)). In the architect's words, MEV was chosen for this project because *'I've found it works' (Christopher)*. Not only has he chosen

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[134] Text in bold is author's emphasis.
[135] The design team went on to design two subsequent schemes together which sought to address some of the issues identified in the first phase.
[136] Author unknown.

the same overall ventilation strategy but the detailing is also similar, with the air handling unit (AHU) located in the loft, and wall-mounted trickle vents used to supply air (as opposed to more conventional, window-mounted trickle vents) (Figure 77, p.290).

The ambitious and somewhat contradictory aspirations of the design team proved challenging to resolve, resulting in a physical arrangement which constrains the possibilities of the residents' to make use of the intended night ventilation strategy. As discussed below, this may challenge the sustainability credentials of the scheme, as electric fans and active cooling systems are introduced by residents to tackle overheating.

5.3.2. Residents' and RSL's (re)arrangements

The physical arrangement not only comprises the built 'shell' delivered by the design team, but also the material configuration, and reconfiguration, of the fabric and building components once the residents move in. In Case A, the rooflight is an important component in the night ventilation strategy, as explained by the architect's description of how he imagines the homes are cooled (5.3.1). However, after visiting the homes and speaking to the residents, it became clear that at Case A the practice of night ventilation was something which only existed in the imagination of the architect, and was not being performed in the inhabited homes. The following quote suggests that the architect is unaware of the residents' struggle to 'do' night ventilation, and that he came to the conclusion that once residents were informed of how to cool their homes at night, the issue had been resolved:

> *'Initially some people had problems with overheating. Which once they got the night vent thing working I think it's fine.' [Christopher]*

Despite this, and regardless of whether the fabric envelope is conducive to night ventilative cooling or not, there are a number of other reasons why the rooflights tend to be left closed at the times when they most need to be open. For example, concern about insects entering through the rooflights is raised by Sabeen.[137] This resident is very afraid of insects, as are her children, and believes that she and her family would not be able to sleep if they left the rooflight open at night, as they'd be so worried about *'the little creepy crawlies coming in'*. As a result, the family are unable to participate in the night ventilation cooling strategy that the architect's design anticipated:

> *'Me and my daughters are quite scared to keep the windows open, because they said "oh, open the skyline, sort of, in the night time, it cools everything down." But I can't do that, I said, "we'll be forever-- won't be able to sleep properly."' [Sabeen]*

[137] The idea of shutting openings at night to prevent insects getting in is also raised in relation to window opening by Dan (Case A).

Instead of using the rooflights at night, these residents open them during the day, closing them at '*six o'clock* [….] *as soon as the evening starts'* because '*you get bugs and mosquitos and things like that coming in, so they shut at that time'*. These homes are located close to a canal which may explain the presence of mosquitos and other insects in the area.

Another physical entity which constrains the use of the rooflight as intended is water, in the form of rain. Several residents raised the issue that they are unable to leave the rooflights open at night time, in case rain gets in and damages their home. Fara explains that although the RSL showed them how to operate the rooflights, her family '*asked them to close it up again'* and do not use the one in the hallway so that rain does not get in. Previously this family had accidentally left a window open when they went away on holiday, which then warped in the rain and no longer closes tightly; this event may explain their reluctance to engage with the rooflight (Figure 41).

Figure 41: Damaged timber window frame (Fara, Case A)

Karen is also unsure about using the rooflight at night as they '*know that next door ended up getting very wet one night'*:

> *'We have to sort of check during the summer if we're going to have any rain, and we just close them because we're never quite sure.' [Karen]*

As well as the presence of certain unwelcome entities (e.g. insects and rain), the absence of a certain component can also constrain the ventilation arrangement of a dwelling. For example, when residents first moved into these homes, there was virtually no way they could reach either of the two rooflights which were located high above the hallway and in the master bedroom (Figure 42). Ali explained how, after enduring their first *'oppressively hot'* summer, '*eventually* *we got them to give us some poles'*, which enabled him and his family to open and close the rooflights, which '*really eases everything in the house'*.[138]

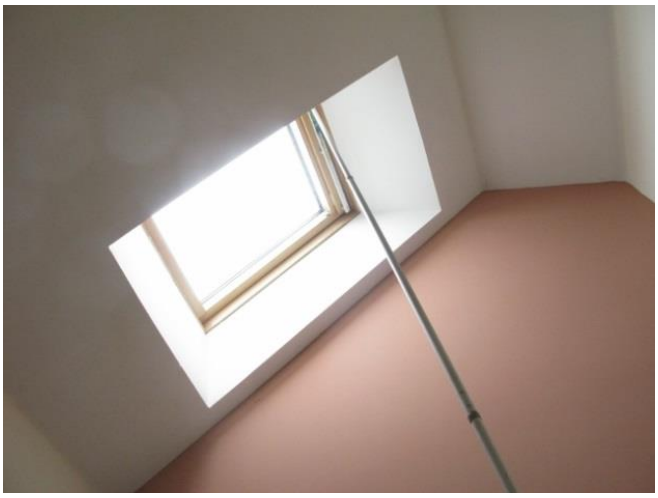

Figure 42: Rooflights cannot be opened without use of extended pole (Ali, Case A)

A similar incident was reported by one of the residents at Case C, although the architect believes '*they were supplied in the first instance. I don't know, maybe they got lost or something'* (Helen):

> *'When we first come we were just looking and saying "how do we open the window?" Because we didn't know. And then after two or three weeks there was somebody coming from the builders, because they were doing the painting things, and they said "we forgot to give you this."' [Maria]*

This example has demonstrated how the arrangement of the rooflight and several other physical entities within and around the homes, such as insects, bodies of water and weather systems, has constrained the possible courses of action in relation to this component. Simultaneously, the presence of another component, the pole, was pivotal in enabling at least some of the residents to attempt to perform night ventilation as the architect imagined they might.

From the above analysis it may appear that some residents prefer to tolerate overheating rather than risk letting water into their home; however, they may simply have found a preferable material arrangement, one which enables them to stay comfortable without worrying about rain ingress. All five residents interviewed at this case were using electric fans in their homes to supplement the ventilation and to reduce overheating during periods of hot weather. In addition, two of the residents had purchased freestanding air-conditioning systems to stay cool (Ali and Pamela) and a third was considering doing the same (Karen). This was also observed at both of the other case studies; overall, nine out of the fifteen residents interviewed for this thesis had

[138] It was observed that at Fara and Karen's homes the pole is more or less permanently fixed to the rooflight. Only when the rooflight is opened does it come off and hang on the wall where a fixing is provided.

purchased electric fans or air conditioning for use in their homes. Instead of settling for the physical arrangement provided by the designers and their landlords, residents have actively introduced additional ventilation components, making their own contribution to the material configuration of their home (Figure 43). This has the potential to negate the intentions of the original low energy design.

Figure 43: Selection of electric fans observed during fieldwork. Clockwise, from top left Sabeen (Case A), Maria (Case C), Pamela (Case A), Joy (Case C) and Karen (Case A).

At the time of the fieldwork, Case A had been inhabited for eight years. Shortly after completion, the design team carried out a POE of the buildings to investigate thermal comfort and energy performance. Additional investigations were being carried out by the RSL at the time of the PhD research, as part of the 'Green Doctor' programme, to help residents use less energy at home.[139] By doing this evaluation, the RSL have identified many of the constraints discussed above and are aware that *'a lot of people are resorting to fans because of that'* (Eddie):

> *'It's not far from the canal and they've had sort of mosquito and wasp infestations so-- and there are several families who've said "we don't open the windows in the summer because we're just getting--", you know, the little kid's been to hospital with a wasp sting or they wake up and there's a mosquito there.' (Eddie)*

They are also considering solutions to reduce overheating, by trying to enable the residents to open the rooflights more often. One strategy discussed by the RSL's Sustainability Manager is to install '*insect screens'* to the openings, to keep out unwanted creatures, and to enable the use of windows during the evening and at night time, although this may be hard to achieve with high level rooflights.

Another resident explained how the RSL is investigating '*the angle that we can actually open it without the rain coming in*' (Karen) to help alleviate chronic overheating in her home. Another addition to the building fabric which the RSL are considering is installing shading at Karen's property, to limit solar heat gains. Figure 44 illustrates how the orientation of this particular dwelling has made it particularly susceptible to overheating.[140] The resident explained that '*they want to put some sort of porch over this window so that the sunlight doesn't come in directly*'. She goes on to say that '*some of the back ones have got both I think but we didn't, we didn't have those. I think because of the way our garden faces they didn't think it was necessary but obviously I think they're getting to the point now where it is'* (Karen).

Karen also mentions that the RSL are considering '*putting a back door into the kitchen […] to get some more airflow coming through*', though she was not certain if this would ever take place. Figure 45 shows the location of existing doors and windows at the property as well as the proposed location of the new back door and porch.

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[139] At this scheme, Eddie and Yvonne were both responsible for conducting the Green Doctor visits which are discussed in this section and it is unclear whether the organisation Groundwork were involved at all. However, as 'Green Doctor' was the term used by the RSLs, for consistency it will also be used herein (see 7.3.3).

[140] Although the design has made use of some passive design strategies, such as large windows, low U-values and an airtight envelope, there is presently very little shading. The exception are small overhanging eaves; however, it is uncertain whether these were intentional or simply a conventional and straightforward construction detail.

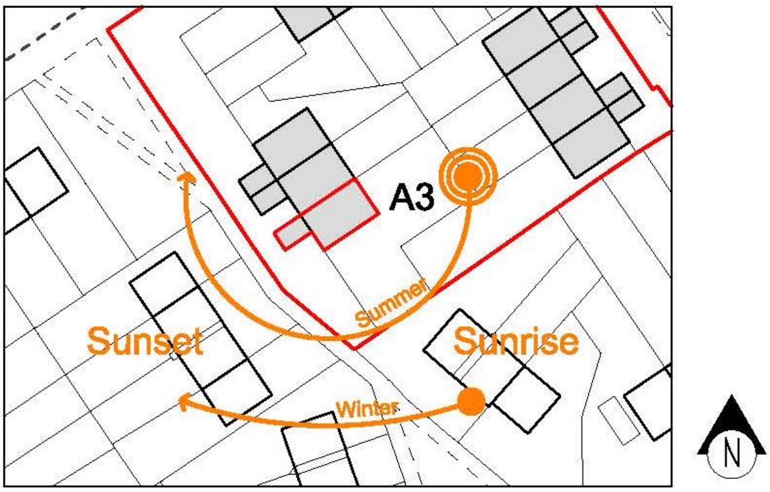

Figure 44: Case A site plan showing movement of sun across house (Karen, Case A) (1:1000)

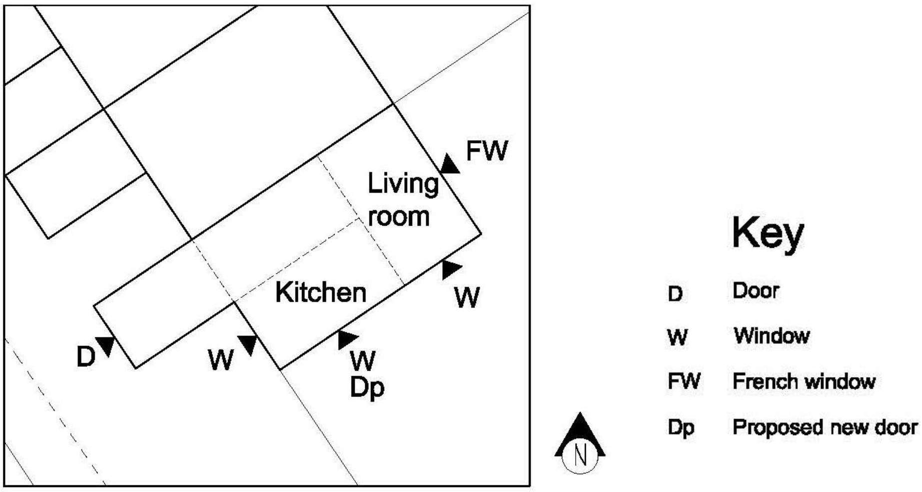

Figure 45: Schematic plan view of house A3 (Karen) showing orientation of existing doors and windows and proposed location of new door (not to scale)

This section has discussed how the intended and designed arrangement is not always materialised in the complex constructed reality of the homes. These findings denote occupants' tendencies to either resist or adapt to technologies over which they have no control, in terms of installation or competence to operate. The next section builds on this to consider how the process of inhabiting the arrangement can add further constraints to the way a dwelling is ventilated.

5.4. Inhabiting the arrangement: The imagined 'empty' house

In this section, all three cases are revisited to explore how people rearrange and modify the space as they inhabit their house or apartment and make it into a home. This contrasts the inhabited arrangements with the construction drawings and diagrams, the latter of which always illustrate empty spaces featuring unobstructed air paths through which ventilation is free to flow.

This difference between design concept and reality has the potential to interfere with anticipated airflows and to hide critical components of the system, as discussed below.

5.4.1. Obstructing airflows

Ventilation relies on the movement of air into and out of the building and ventilation rates are calculated according to the size of openings provided for this purpose. As air passes through the building it will encounter some resistance, the level of which will depend on the layout of the internal spaces. Therefore, it is important to minimise obstructions to the intended ventilation path to maintain adequate airflow rates (Mumovic and Santamouris, 2013).

Vents

The inlet vents at Case A are located in the walls and not, as is more conventional, in the window frames. Several vents at this case were found to be obstructed by pieces of furniture. For example, in Ali's house, a bookshelf has been fitted in front of the wall vent in his daughter's bedroom (Figure 46). He complains that *'all the bad smells in the house seem to hang out here',* which might be connected to the obstructed vent. Another example in this dwelling is the wardrobe in the master bedroom which is also positioned in front of the wall inlet, potentially obstructing the airflow to and from it (Figure 46).

At Karen's house, the master bedroom furniture has also been installed in such a way that the wall inlet is blocked by one of the wardrobes, and access to the main windows is also obstructed (Figure 47). In another room in the house, a child's bunk bed had been recently replaced with a lower bed, revealing a previously hidden vent with a broken cover. A broken vent cover was also found at Fara's house. She explained how '*one of the kids broke it off, then we had to put it back on with Selotape'*, something which could certainly be obstructing the airflow into this room (Figure 48).

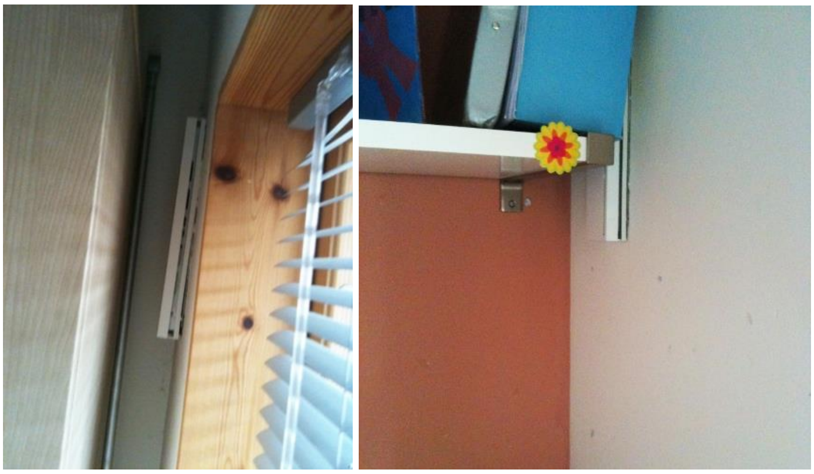

Figure 46: Pieces of furniture obstructing the wall inlets in master bedroom (left) and daughter's bedroom (right) (Ali, Case A)

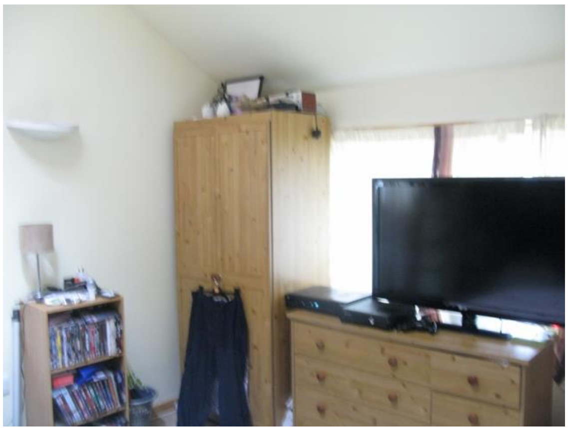

Figure 47: Wall inlet hidden behind cupboard (Karen, Case A)

Figure 48: Wall vent cover repaired with tape (Karen, Case A)

Fara's house is exceptionally densely occupied. As there are 11 people living in a four bedroom house, the family have had to be creative with how they use the space, with the living room doubling as a master bedroom and pull-out mattresses used for the smaller children. There is little furniture in the dwelling; in particular, there were no wardrobes. Instead, clothes are hung on rails suspended from the mezzanine storage area, as well as from the living room door. It is unsurprising that damage from wear and tear occurs in a house that is so densely occupied. The adult residents in this house use a fridge as a filing cabinet to protect important documents from one of their eight children, who has a disability. For the same reason, the thermostat has been taped over so that the settings cannot be tampered with.

The positioning of the vents in the wall, rather than the more conventional arrangement where trickle vents are located within the window frame itself, may explain why more obstructed vents were observed at these properties than at the other two cases. It would be more surprising to encounter furniture placed directly in front of windows than against the wall. However, this was actually observed in Karen's kitchen, where additional white goods have been installed in a position that blocks access to the side window (Figure 104).

In contrast, at Case C, where trickle vents are located within the window frame, only one instance was observed where windows had been covered up, blocking the vents. The resident, Carla, had positioned the wardrobe in her bedroom in front of a large balcony window, so as to reduce the draughts which she felt were making the house cold. She believed that her strategy was effective, although she noted that '*it's costing me the lights'* as the room is now much darker. Carla's house was quite full, with several pieces of furniture and other possessions in each room. For example, there is a pile of books and boxes on top of the high level kitchen units. These are stacked up right below the ceiling extract grille, which is located beside the wall, close to the corner of the room, in a way that they could potentially interfere with airflows if the pile were to get any taller (Figure 171, Appendix). A similar arrangement was observed at Sarah's house, where a bathroom cabinet had been installed directly under the extract vent, with various toiletries placed on top of it (Figure 176, Appendix).

There are no trickle vents at Case B as air is both supplied and removed through ceiling terminals, none of which were found be obstructed at the visited flats. However, in one flat, an area of exposed ductwork in the cupboard where the fan unit is housed has been squashed by the residents' possessions. Anthony explains how *'we're short of storage space. So every available nook and cranny is filled'*. This includes using the AHU as a makeshift wardrobe (Figure 49). Originally the ductwork had been boxed in but this was removed at the commissioning stage and not replaced. The current arrangement of stored items competing for space with ventilation ducts risks damaging the performance of the ventilation system.

Figure 49: Fan unit ductwork squashed by residents' possessions (Anthony, Case B)

Gaps under doors

According to ADF a 10 mm gap is required under each internal door in a dwelling to enable the passage of air between connected spaces (as discussed previously in section 2.1.5, (HM Government, 2010a)). Without this gap, the air path would be obstructed whenever internal doors are closed. At Ali's house, the residents have laid a fitted carpet over the wooden floors in the living room. The carpet, combined with the '*warping effect of the floor in that corner'* which has caused the floor to rise in places, means that there is now no ventilation gap under the door between the living room and hallway. The architect mentioned that this *'deflection in the floor'* was one of the main problems that had arisen during construction:

> *'As a consequence really of the builders-- well the floor construction got wet and the sheeting on the top of it wasn't really fixed properly and then they put the finished flooring on top of that and it was all a bit-- and some of the houses, two or three of them, they took it up and redid it which made it much better.' [Christopher]*

Despite the remedial action, the problem remains in at least this one property. The combination of this deflection and the layering of a carpet over the top of it is now restricting the movement of the door, as well as partially obstructing one of the air passages required by ADF (HM Government, 2010a). This is an example of how some of the constraints and enablements of technical systems cannot always be foreseen, but rather emerge from technical practice and quickly become enmeshed into the performance of technical systems.

Four residents at Case B had also installed fitted carpets in their new apartment (Betty, Paul, Anthony, and Steve). Anthony explains how '*we never have the doors closed';* therefore, if this is true, the movement of air between the habitable and wet spaces is unlikely to be obstructed by the carpet in this particular dwelling. On the other hand, Steve found that he was unable to close the doors in his flat after having a new carpet laid:

> *'I bought my own carpets, moved in, got them laid down. Then I got a text from the people who done the carpet [….] the carpets were so thick the doors were undercutting the carpet, really cutting in [….]. Do you know what I mean? When I put the door on "krkrkrkr", really bad'.*

His brother's friend, a carpenter, came to fix the problem by sawing off part of bottom of the door. However, he was presumably unaware of the 10 mm rule, advising that '*I don't want to take too much off otherwise in the winter [when] you shut your doors you get a draught'* so that now the carpets fit snuggly up to the bottom of the door, which prevents air movement out of the room when closed. The resident was upset by this experience and noted that his expensive new carpet had been damaged through the effect of the sawn door scratching against it every time it is opened or closed. Fortunately, the arrangement of ventilation inlets and outlets in this apartment means that the ventilation strategy does not rely on air passing underneath this door; this is because both inlets and outlets are present in the open plan living and kitchen area, as well as on the other side of the door, effectively creating two separate ventilation 'paths' which do not cross (Figure 50).

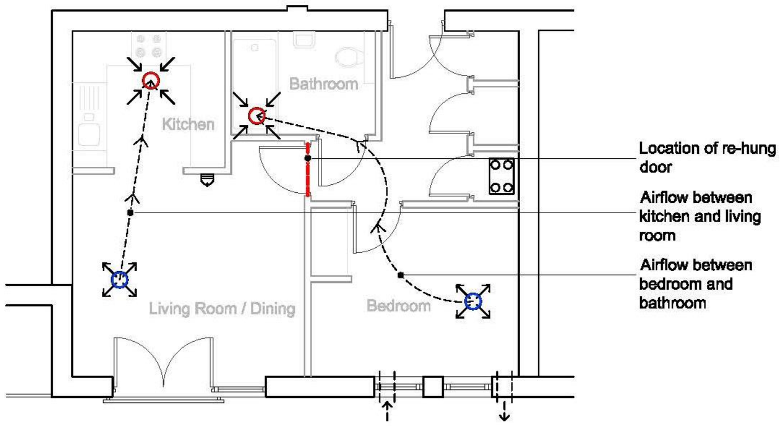

Figure 50: Anticipated ventilation paths through flat (Steve, Case B) (1:150)

Although the extent to which these obstructions have affected ventilation at these particular dwellings is uncertain, the lack of ventilation gap is a potentially serious departure from the design intention, particularly in those dwellings, such as Ali's house, where the ventilation strategy anticipates the free movement of air into and through the living room, to the kitchen, where stale air is finally extracted (Figure 51). Furthermore, issues may arise when the residents change, as the new tenants may not leave doors open all the time and could end up suffering the effects of poor ventilation.

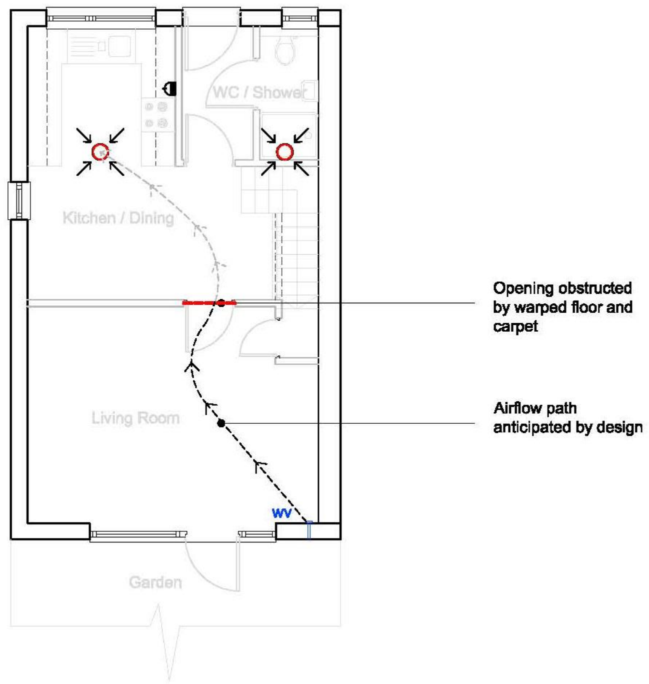

Figure 51: Plan showing how the ventilation design could be compromised by poorly installed floor combined with resident's modifications to building fabric (1:150)

5.4.2. Hidden components

The process of inhabiting the home and introducing one's own belongings into it may cause certain components of the ventilation system to become hidden within the overall arrangement. Case A is useful for considering how this can happen, as these homes had been occupied by the interviewed residents for the longest period out of the three cases (4 to 8 years);

consequently people have had the chance to fill them with their possessions and adapt them to their needs.

Several of the residents at Case A only found out about the presence of the AHU in the loft when the RSL came to do the maintenance for the first time.[141] Karen recalls how '*we only discovered it was there last year when they actually came and said we should have been maint-- we should have been doing a yearly […..] maintenance on this*'. This suggests that they had lived at the property for seven years before any maintenance was carried out on the unit: *'It's part of our storage area and the door was closed when we moved in. I didn't even open the door and never thought there was anything behind it'*. She explains how '*the maintenance guys* […..] *literally turned up one day and said "We need to do it" and they couldn't even get up there because my storage area was absolutely jam packed*.'

On the day of the interview this house was visibly quite full of furniture and other possessions and the mezzanine was stacked full of boxes, restricting access to the attic (Figure 52). Furthermore, the airing cupboard was extremely full of stored items, making access to the boiler virtually impossible, and suggesting that the boiler is also not being interacted with regularly and that the cupboard is not being used for its intended purpose of drying laundry (Figure 100, Appendix).

A similar incident had occurred at the home of Sabeen. Here, it was also noticed that the mezzanine storage area above the bedroom was quite full of possessions, restricting access to the loft space (Figure 43). Sabeen mentioned that they were also unaware of the AHU until maintenance was carried out for the first time, after six years living in the house. She explains how 't*hey said they were going to clean out one of the extractor fans and I was thinking "oh they're going to clean all these [extract vents] out"*', and then was surprised when they went up into the loft and '*cleaned out this huge big-- this big fan thing in there'*. It was only then that she *'realised it's linked to that [extractor]'.* Before then, she '*didn't have a clue'*.

In both of these homes part of the ventilation system was 'hidden' during the residents' process of furnishing and occupying the home, only to be revealed during a delayed routine maintenance visit from the RSL. In contrast, one of the children living with Karen had made her own modifications to the space without obstructing the wall vent which was present in her room.

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[141] Although the precise reason for this delay is unclear, at Case A both the POE consultant and the architect do not think any maintenance is required for this system. The architect has the same system in his own home and hasn't touched it for 20 years *('it's not designed really to be accessible'*). However, he later admits that his own home, which he built himself, probably isn't as airtight as the new ones and therefore perhaps the fan isn't having to do as much work in his house. As this architect prepared the original O&M manual for this project it's possible that he also advised the RSL that there was no maintenance requirement. This is discussed further in section 7.3.3.

This resident had carefully arranged pictures of her favourite boy band around the wall inlet, effectively hiding it, yet without compromising any of its function (Figure 53).

Figure 52: Access to loft blocked by boxes (Karen, Case A)

Figure 53: Wall inlet surrounded by posters and cut outs (Karen, Case A)

At Case C, the PSV system has few visible components to hide or obstruct. This limits the potential for residents to interact with or even notice the ventilation technology. Sarah was alarmed to see '*smoke coming off the chimneys'* whilst out in the garden and was reassured when she was told that '*that's the ventilation working'* after raising this with the RSL. Another largely invisible component of the homes with PSV is the 'breathing wall' which was intended to allow moisture to pass through and was designed to prevent condensation on internal surfaces.[142] However, Carla reported that after they moved in the '*eco-friendly'* paint was *'just peeling off'* so she painted over it with *'other paint'*. Although there was no visible evidence of

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[142] According to the aforementioned student dissertation (Anon., 2009). Furthermore, the RSL technical manager, Michael, mentioned that the '*walls were made to breathe'*.

condensation at this property, there is potential for the problem to arise in the future as the original design intent has been modified by the resident's actions.

As internal spaces are filled up with the various entities that comprise a living space, the volume of air remaining in the house is reduced. This will increase the concentration of any pollutants which are present in the house, potentially increasing their harmful effects on the health of the building and its occupants. This is something which is likely to get more noticeable as homes are occupied for longer. The interior spaces at Case B were relatively sparse compared to the other two cases, as the residents had moved into their homes much more recently. Hence, the examples above are mainly drawn from Cases A and C, which had already been occupied for several years at the time of the interviews.[143]

5.5. Summary

This chapter focused on the physical arrangement of the case study dwellings and their ventilation components. The analysis revealed how this arrangement is not only the materialised design intent of the design team but is also shaped and constrained by regulation, design targets and various other conflicting interests. Ventilation is just one part of the arrangement, vying for attention with other elements, and therefore is not always considered as early in the design process as would be ideal.

In addition, the process of turning a house or flat into a home, by furnishing and inhabiting the built fabric, creates spaces that are different from those indicated by architectural drawings. Furthermore, unlike the design documentation, these arrangements are constantly changing and never 'fixed'. For example, ventilation paths are obstructed by fitted carpets, ducts are squashed by a makeshift wardrobe and electric fans are purchased to reduce reliance on night ventilation and to prevent unwanted living creatures entering the family's space. This (re)arrangement is thus the stage on which people's ventilation (and related) practices are carried out and their actions should be understood in relation to these modified spaces rather than the empty and pristine ones presented in the design documentation.

The range of examples presented in this chapter demonstrates how arrangements (and therefore practice-arrangement bundles) can exist at different scales, from the obstruction of a single trickle vent, to the appointment of an entire design team. The next chapter will develop

[143] As well as filling up with voluminous possessions, the number of electrical appliances may also increase with occupation. This could contribute to the heat gains and exacerbate the already overheating-prone situation. Several of the homes at Cases A and C were found to be full of various additional appliances. For example, Karen's house had several large televisions in the living room and master bedroom and a computer and several games consoles in her sons' bedroom (Figure 98, Appendix), as well as extra white goods in the kitchen. A large top-loading freezer and a running machine were also noted in Carla's house.

these ideas by examining how certain bundles of activities could comprise a domestic ventilation ‘practice’.

Chapter 6: Ventilation practices as complex bundles; routines, lifestyles and past experiences

6.1. Introduction

6.1.1. Aim and structure of chapter

The previous chapter explored how the material configuration of ventilation systems within homes is not only shaped by regulation, performance targets and design intent, but how the occupants themselves play a role in arranging the space around them. In several examples the ensuing physical arrangement prevented residents performing, or ‘practicing’, ventilation as the designers intended.

The aim of this chapter is to demonstrate that ‘ventilation practice’ does not relate to a specific set of actions or tasks, but is a looser term which encapsulates a range of activities that are carried out in people’s homes, as they go about their daily lives. Many of these activities are themselves part of different, and often multiple, practices, rather than simply about ‘doing’ ventilation. The emphasis here is on people’s experiences of the ventilation technologies, and how they incorporate them into their everyday activities; it is these bundles of activities that form the rich tapestry of ‘living’ that comprises a ventilation ‘practice’.

The framework developed by Gram-Hanssen (2011) for empirical research into consumption practices is used to structure the chapter. The framework, introduced in section 3.4.1, comprises four elements which are used to analyse the residents’ reflections on living in, and ventilating, their homes:

- **Know-how and embodied habits:** A practical and bodily understanding of doings, sayings and actions, generally embodied within routine and everyday activities.
- **Institutionalised knowledge:** Technical knowledge, cultural myths and rules, e.g. instruction manuals.
- **Engagements**: Meanings, morals and goals; that which is important to the practitioner.
- **Technologies:** The physical fabric of the building and the material 'artefacts' with which people interact.

6.1.2. Talking about ventilation and air

Up to this point in the thesis, much of the discussion has used the terms ‘ventilation’ and ‘ventilate’ to discuss the phenomenon of air moving through homes. However, these are not necessarily terms which are used by laypeople, who, it appears, may be more comfortable talking about ‘airing’ and ‘fresh air’. During the interviews, questions using the word ‘ventilate’ were often met with confusion by the residents, some of whom conflated ventilation with heating and staying warm. For example, when asked how she felt about the ventilation in the living room, Carla replied that '*the heater will have to be on; if the heater is off it's too cold*'. A similar unfamiliarity with the term 'ventilate' was expressed by two other residents, Fara and Karen:

> *'CB: Could you say something about how you ventilate this house?*
>
> *Fara: Because there's a lot of us it's always warm anyway'.*
>
> *'CB: Could you say a bit about how you ventilate this house?*
>
> *Karen: Sorry how do you mean? Just by, what? For heating and stuff or?'*

There is also some ambiguity around the phrase 'fresh air', a term which is used numerous times in ADF 2010 without definition (HM Government, 2010a).[144] Carla questions what is meant by the term 'fresh' in relation to air by asking '*Fresh? What would fresh be? What would that look like?*' Her understanding of the word '*fresh*' relates to cooler temperatures, rather than the author's interpretation that '*fresh air'* refers to 'clean' air, i.e. that which is free of pollutants.

> *'Maybe when I'm outside in the garden […] it's fresh. But, because the heating has to be on, it's warm, so it's not that fresh'.*

Carla also answers a question about the 'air' in the house with *'I don't have-- because it's off and on so don't really know'.* This hints at the notion that the bundles of activities relating to heating and ventilating may be more closely connected than those of other tasks. Only when discussing other everyday activities did an idea of what a ventilation practice could be begin to emerge.

6.2. Ventilation know-how and embodied habits: temporal routines and past experiences

All the residents who were interviewed described different embodied habits and routines relating to ventilation.[145] Many of the routines were presented in relation to a particular time of day. Notably, these routines comprise 'opening' and 'airing' using windows, doors and rooflights, especially in the morning and during the night. Other physical components of the ventilation system were rarely referred to in this context.

6.2.1. Daily routines of airing and opening

Mornings are a time for getting out of bed, preparing to go to work or school and gearing up for a new day. Daily opening of windows to *'let the fresh air in'* (Ali) are discussed alongside other morning activities such as '*do*[ing] *the beds'* (Ali) and refreshing a *'stuffy'* (Sabeen) home after a

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[144] Nine times in total.
[145] Each participant's description of their activities relating to ventilation was illustrated in a diagram which was used to record the detailed interactions between practices and arrangements and to inform the analysis presented in this chapter. An example of such a diagram is reproduced in Appendix B.5, Figure 68.

night's sleep. This frequently takes place *'early in the morning'* (Sabeen) or *'first thing in the morning'* (Dan), shortly after getting up. For residents who work at night, windows can be used to air the home while other members of the family are out:

> *'In the mornings [….] everybody goes to school. Because I do a night job. So when I come in the morning I do open the doors so that at least [….] we get fresh air inside and then after some time then I close it.' [Joy]*

All members of the household can be involved in the opening, but not always closing, of windows. Multiple entities (both people and other organisms) are implicated in Karen's weekday routine, including her children, her mother-in-law, and the family dog:

> *'They tend to leave them open and [….] I'm gone now before they go to school in the mornings [….] so I can't check if they're done. My mother-in-law does pop round at midday to let him out [the dog] and goes round and checks.'*

Another cluster of airing activities takes place in the afternoon and evening, as people return from work. Several residents living at Case B described a routine of opening windows both before going to work and as soon as they return. For one resident, this routine continues throughout the year, regardless of the weather. Dan explains how '*in the winter I'll literally come in [….] from work about half four and then I'd open them for an hour or so'*. Another resident notes how on warmer days he finds his flat *'roasting'* when he gets home from work *'because the sun's beaming'.* He opens both the balcony door and living room windows because *'you can't breathe in here'* [Steve].

As an activity, airing is seldom performed entirely in isolation. For example, Maria's daily window-opening routine is intertwined with her and her family's busy schedule, as she comes home between jobs to open the windows, collect her son from school, and to prepare food, before finally going out to work again in the evening:

> *'We are probably opening them in the mornings for about a couple of hours and sometimes in the afternoon if it's sunny for a couple of hours as well, and then we close them again. [….] It's me coming in between hours. I work in the morning and then I come back and then I go again and then I come back.'*

Sabeen's family keep windows open for much of the day, but then close them in the evening when it starts to get dark, thus preventing insects from entering the house (see section 5.3). She explains that '*as soon as the lights go on they-- we draw the curtains [….] because we sort of like our privacy' [Sabeen].* Their evening routine comprises shutting windows and closing curtains simultaneously; here there are two types of interaction with the windows taking place as the family settle down for the evening, one for privacy and the other to keep out unwanted intruders (insects), hinting at a deeply ingrained embodied habit.

Nights are generally a time for sleeping and rest. Window opening is often performed in advance of getting into bed, as part of a bundle of activities associated with preparing to sleep.

Some residents leave windows open at night all year round, whatever the weather (e.g. Anthony and Paul). Steve sleeps with the window open, otherwise *'it's too hot'*. He says that '*I don't get cold easy'* because he performs a manual job, based outdoors. Others feel unable to do so even when it's hot; for example Dan explains that although *'it does get a bit stuffy at times [….] I've got a phobia against spiders so I'm not [laughs] I'm not one for leaving windows open at night, no.'* This resident feels vulnerable whilst sleeping; fear and concerns for safety constrain the activity of leaving a window open at night, preventing him from ventilating as much as he might like. Other residents feel reassured by the feeling of security afforded to them by the *'safety latch'* (Sarah) which enables them to leave their bedroom window open a small amount without having to fear an intruder breaking in while they sleep.[146] As sleeping is an activity which (usually) lasts for at least several hours, windows left open at bedtime are likely to remain so until morning, when they may become caught up in the bundle of morning routines discussed above.

This analysis described a series of clusters of everyday activities which share certain commonalities, despite taking place in spatially disparate dwellings, with varying family characteristics and physical arrangements; although never identical, these related activities are being performed simultaneously, at multiple locations, over the course of the day. These embodied routines are part of a range of daily tasks, such as caring for children, homemaking, staying safe and looking after one's health, suggesting that ventilation may be part of a set of other practices which people carry and perform, rather than an isolated practice in its own right.

6.2.2. Seasonal variation in routine ventilation activities

Certain routinised practices are particularly prominent around certain seasons. For example, although the data suggest that people open windows all year round, some seasonal variation exists between spring, summer and winter. During summer there are more hours of daylight and temperatures are typically warmer than in winter. As well as windows, doors are frequently mentioned in relation to summertime and warm weather, with a notable increase in references to combined window and door opening at all three cases. For example, Maria explains that '*when we are home we just open the windows, open the garden doors, especially now that it's spring'*. She then adds that *'during the winter it's more difficult'*. This reveals a connection between window opening, comfort seeking activities and the external physical environment.

As discussed in Chapter 5, summertime overheating is a concern at all three cases. Residents take a progression of steps to achieve thermal comfort,[147] depending on the resources available to them, but typically starting with windows, then progressing to doors, rooflights and eventually electric fans and perhaps even active cooling systems. Pamela uses a combination of doors

[146] Overall, nine residents (3 at each site) report leaving windows open at night while they sleep, either occasionally or regularly.
[147] See 2.1.3 for definition of thermal comfort.

and windows to attempt to cool down internal spaces. She describes how '*in the summer this place is boiling hot. Ventilation is very, very, limited, unless you've got all the doors open and all the windows open*.' Where this combination of actions is still insufficient to provide comfortable conditions, some residents go on to open up the rooflight. Opening rooflights seems to be a secondary activity, perhaps because they require a more complicated and coordinated set of actions to interact with than opening a window or door:

> *'The* [rooflight] *thing up there on the stairs [….] that's open mainly in the summer sort of during the sort of late morning. Early morning, I would say first thing is the bedroom windows that I'd open and I'd probably do both if it's quite a nice day; if it's not at least the one small one.' [Sabeen]*

At Case B there are no rooflights, and so the next step is to use fans to supplement the ventilation: '*I just open the big French doors there and leave them wide open in here and bring out the fans'* [Paul].

Window and door opening in summer is not just about comfort. Residents spend more time outdoors during warmer months. Weather permitting, Sarah and her brother like to *'come downstairs and smoke on the front door or front garden or the back garden'*. The extra airflow provided by this activity is part of their smoking and socialising routine; here, ventilation is interconnected with several other social practices. Windows and doors are opened less during winter. However, there are still some residents who are reluctant to ever close the windows completely. Anthony's bedroom windows are open *'almost 24 hours a day. Unless it gets very cold or wet do we close them';* similarly, their living room window is *'usually open from sort of spring time onwards'*.

The houses at Case C are equipped with trickle vents which should, in theory, be left open all year round to provide sufficient air exchange (HM Government, 2010a). However, while Joy's comment that '*in the winter we don't open the doors or the windows much. We only open the small bits, I don't know how it's called, that's all we open'* suggests that trickle vents *are* providing background ventilation during winter, Sarah describes how the vents were all closed during winter and are only just being opened again as the weather improves:

> *'Yeah, but only because we're only just coming out of the winter [….] due course that'll start opening.'*

Seasonal ventilation activities differ from daily routines in that they only take place at certain times of year or under certain conditions, whilst at other times they are not relevant. When this occurs they may even disappear, unless they are part of other bundles of activities which can keep them going throughout these periods. For example, certain doors are opened each day to enter and leave the house or to let pets into the garden. Other openings, such as trickle vents, may be exclusively part of the summer airing routine and therefore could lie dormant through much of the year, and only be reawakened gradually as the seasons change.

6.2.3. Past experiences

Ventilation 'know-how' and embodied routines may develop over the course of people's lives; therefore, a discussion of residents' past experience is relevant in the context of how they ventilate their current home. For example, Ali explains that some of their practices have gradually changed as they settled into their new home which is much warmer and dryer than their last one. Ali experienced health problems in his previous home owing to cold and damp conditions which caused mould to grow on the walls. He observes that *'we've had to adapt to the house. […] So we had to rethink how often we need the radiators on, rethink closing the doors etcetera, because in the previous property you would close the doors to make sure the heat stays in'.* However, as a father to three young children, Ali also takes pleasure and comfort in recreating his childhood experience by enacting his parents' morning routine for his own family:

> *'It's learned behaviour from when you're a child. Even your parents, your mum would come into the room, "wake up kids", turn the light on open the blinds, open the window. [….] It's almost a comfort to people to do-- be able to do things that they remember their mums and dads doing.' [ALI]*

Despite now living in a property where the ventilation is arranged in a way that doesn't require additional window opening, his morning window opening routine has become embodied after years of repetition, and may be challenging to change.

Embodied know-how based on past experiences can also be a source of confusion. For example, at Case C, Carla references her previous experience of ventilation technologies to explain why her current PSV arrangement isn't working. She states that '*in the old house you can actually, there's a switch that you put when you need the air to circulate. […] You pull it and then it goes on'*. While her previous home had a demand controlled fan in each bathroom and kitchen, her present home has neither. Furthermore, her workplace WC also relies on a mechanical fan for ventilation:

> *'The toilet-- like my workplace doesn't have window. But it doesn't linger. So there is something they must have, like a fan or something that they must have put, that takes the smell out. But whereas it's not like that here.'*

On the other hand, at home, *'when you use the bathroom the smell lingers on'*. Carla is unable to 'see' ventilation happening. Instead, her understanding of ventilation is informed by sound and smell. Her previous experience of the sound of mechanical fans contributes to her awareness of ventilation. In the current house, where the ventilation system is silent, it is harder for her to tell if ventilation is taking place, and the fact that smells are lingering suggests to her that it isn't.

> *'And there you can see it or even hear it working, you see the practicality of this, but with this one it's just there, you don't know what you're doing and you're not seeing even the effect […] It could be working okay but how? To what extent is it working?'*

6.3. Institutionalised knowledge: Technical understanding and rules

6.3.1. Following rules

At all three cases residents discussed verbal and written instructions about ventilating their homes. For example, at Case B, Betty recalls being told '*don't touch anything'* when she moved in, as does Paul. Betty also mentions how she is *'not allowed'* to leave windows open at night after being instructed to *'lock up at night because it's not safe'*. Both these residents have accepted the rules and appear to be abiding by them; for example, Paul says *'I'm a good boy. I do what I'm told.*' This contrasts with Anthony, who questions whether it is really necessary to keep the MVHR switched on, as him and his wife keep the windows open at night. He is concerned about the running cost of the system:

> *'If we have the windows open do we need this on? Because it says in the booklet keep it on all the time but it-- I don't know what the running costs of it are.'*

At Case A, Fara recalled being told to leave filter changing to the experts because *'they have to do it themselves because they have a specific filter from the company [….] you can't buy that filter in the shops.'* Here, by following 'rules', residents are excluded from parts of the ventilation practice (e.g. maintenance), particularly those parts relating to unfamiliar or new equipment. Furthermore, elements of a ventilation practice are performed by different bodies whilst still relating to the same physical arrangement (a particular home). This challenges the idea that humans are carriers of a particular practice as, here, separate humans perform different parts of the practice.

Ventilation rules seem to be more about 'not doing' than 'doing'. For examples, at Case C, Maria remembers being instructed to leave trickle vents open all the time and not to obstruct the ceiling vents:

> *'When we first moved, the lady who came to show us the house, yeah, she said "that's ventilations, shouldn't be closed any time. Keep it open it's just to have the air come inside and ventilation"'.*

Whilst Maria did not questions this rule, Sarah does not seem to have heeded the advice, as she described opening up trickle vents after winter, even though she recalls reading the *'welcome pack'* (6.2.2, 7.2.1). Both residents previously lived in very damp and mouldy homes which they blamed for causing their children to suffer from ill health, so it is surprising that only Maria obeys the rule. This suggests that there may be a difference between receiving instructions in person and reading a manual.[148] Not every resident is

[148] Instruction manuals and handover are discussed further in Chapter 7.

willing to follow instructions. For instance, Ali blames the rules for constraining his family's actions and reducing their comfort. He is dissatisfied with the strength of extraction from the kitchen, which he blames on to '*the sealed nature of the house'* which, he says, prevented them from making '*holes in the structure and fabric of it so we couldn't have an external vent here'.*

> *'It's a very small ventilation and it's not very good. And it's not really fit for removing a lot of the smells in the kitchen. Whether it's Asian cooking or any other kind of cooking onions are onions.'*

His comment hints at a cultural sensitivity around accommodating different people's cooking practices. It sounds as though his concerns about the ventilation technology may have been dismissed as due to 'Asian cooking'. Instead, the members of this household open windows when cooking.

At Case B, Paul wrote to the RSL to ask for a cooker hood after visitors to his flat mentioned that they could smell the sausages which he had cooked earlier that day. The RSL informed him that he wasn't allowed a cooker hood until he'd lived there for two years and advised him to use the booster switch instead. However he prefers to use the windows because *'all the cooking smells have got to get out somewhere'*. This comment doesn't acknowledge the MVHR extract vents which are already present in his flat for this purpose. This resident's use of windows is shaped by both institutional and material constraints.

Some rules apply to one household member but not another. For example, Sarah explains how she feels unable to place the same restrictions on her older, middle-aged, brother, who is currently living with them, as she does on her teenage son, who is only permitted to smoke outside the house. Consequently, her brother's bedroom window is left open all year round, potentially contributing to unnecessary heat loss.

> *'We're both in our fifties and he's older than me and it's like telling a child "you can't smoke in your room." [….] In the winter time, yeah, he hibernates upstairs. But he's always got that window open.'*

6.3.2. Healthy living

Several residents use ventilation to alleviate chronic health conditions. For example, Ali explains that his physical health condition caused *'some psychological secondary symptoms'* which were '*really helped [….] by the house'*. He attributes his improvement to the *'openness of the place'*, *'that sense of Swedishness'* and '*the fact that we had a garden [….] you can see the trees outside'*. Sarah states that if she wakes up '*and it's a bit grey'* she opens the front and back doors '*so the air comes through'* until '*it's lifted'*. Compared to her previous home where she felt '*very tired* […] *now I can think broad and wide; I can smile; I can get lost in one of the rooms'*.

On the other hand, Carla is dissatisfied with her ventilation arrangement, which she believes is distributing '*dust*' around her house. She is struggling to cope, and blames the ventilation for exacerbating her family's asthma and making them sneeze as '*they are allergic to stuff like that because they suffer from hay fever'*. This resident is physically and mentally worn out by trying to run her house as she would like to and has even resorted to repainting the internal walls using different paint to see if *'if that will reduce things'*:[149]

> *'I can't really rest; I have to get on and do it. [….] So which is not good for my health either. Instead of me sitting down relaxing all I want to do is tidy up, clean.'*

In some dwellings, windows are opened at night to alleviate health concerns and simultaneously aid sleep. For example, Paul suffers from a sweating condition and '*can't sleep'* unless he has *'a flow of air through'* his bedroom. When forced to close the window, because '*it was very stormy'* and wind was '*blowing the thing* [curtain] *all over the place',* he endured an interrupted night's sleep. Pamela suffers from asthma and notes how '*at night times I suddenly wake up and got an attack coming, especially if my window is shut. Then I'll open it a little bit'*. Although she is disappointed that the new house has not helped her own asthma, she acknowledges that her '*children's asthmas have cleared up',* with the added benefit that they do not get as many colds as they did in their old house, where one child's illness '*would go through the whole of winter'*. Two other residents discussed how their children's allergic symptoms had improved since living in their home (Fara and Maria). These residents explain that their children's asthma was originally caused by exposure to damp and mould in their previous homes. Maria was advised by a health inspector that the '*mould on the ceiling'* at her previous house could *'lead to the problem'* and was relieved that her two children are now *'healthy'*.

The architect at Case A recalls meeting a resident at a different scheme who had *'turned [the MVHR] off because they were saying that it was going to give their-- it was going to give their kids asthma'.* A similar concern was raised by Anthony, who has developed a chronic cough since moving into a dwelling with MVHR.[150] With advice from two GPs he has *'got down to one common denominator: that's this ventilation system'*. The myth surrounding the benefits of outdoor air appears to have endured since Victorian times (see 2.2.2). Fara explains that opening windows at night is *'a good thing',* even during winter. Despite being advised otherwise, regular window opening remains part of this family's ventilation regime:

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[149] Initially, 'breathable' paint was used internally at Case C (5.1.3). It is unclear whether the resident's own paint was also breathable.

[150] Six months at this flat and six months in his previous flat, which was part of the same development and located nearby.

> *'We have been told by the people that came round from [RSL] that in the night none of the windows don't have to be open [….] but we still keep the other windows open during the night.'*

Cultural myths surrounding health have prompted some residents to abandon daily routines while unwell. Two residents explained that they were suffering from colds, and that this was why certain windows were closed. While Anthony kept the windows closed because he was *'just getting over a cold'*, Dan was actively trying to *'sweat it out'* by making the flat warmer than usual. Karen mentions that she prefers to close the bedroom window at night because she has a problem with her back and has '*to be careful about the draughts coming in, obviously*.' Finally, Ali augmented his family's ventilation routine by purchasing a freestanding cooling unit when one of his children was ill. He insisted that '*we don't actually use it as such'*; however, as the artefact is now part of the dwelling, it could become integrated into another practice in due course. It appears that occupants' acute or chronic health status might affect their ventilation practices and may even lead to practices which are energy-inefficient, such as opening windows in winter and using electric fans during summer.

6.3.3. Lack of technical knowledge

There is a mixed level of awareness and understanding of ventilation systems and technologies in the dwellings. Residents are trying to make sense of the systems as best they can, looking for visual or aural clues to detect whether the system is functioning. For example, Ali is reassured that the ventilation is working, because the fans occasionally make some noise. However, although he is aware of the MEV system, he demonstrates some confusion about the details of how it functions. He explains that air is being fed to the trickle vents via the central fan unit, and then pushed around the house; thus he confuses the direction of the airflow and misinterprets the purpose of the wall vents. He also describes the thermostat as *'a Doctor Who contraption'* and *'some kind of Pandora's box thing'* revealing his struggle to relate to this technology.

Betty is not very familiar with modern technology, referring to technological devices as *'fidlies'* her thermostat as the *'old whotsit'*, ceiling vents as '*thingys'* and sensors as *'eco-gadgets'*. Nonetheless, she seems to be coping well with the new MVHR system and is comfortable and content in her home. On the other hand, Anthony shows some mistrust of the unfamiliar technology, arguing that '*I don't think there's any substitute for fresh air [….] it's natural isn't it?'* He also questions the need for MVHR in his home and indicates that he would prefer to live in a naturally ventilated space. He appears confused about what the MVHR actually does, suggesting that the air is not *'natural;'* this resonates with the myth that natural is 'good' and unnatural is 'bad':

> *'Imagine that you're in my position and got, you may have one of these systems, which would you prefer on a summer's day? The windows and doors open or a ventilation system?'*

Fara learned to amend her cooking routine after being told off by her mother, following an alarming event. While cooking, she forgot to press the booster switch and suddenly '*there was* *smoke everywhere in the kitchen'*. After following instructions from her mother to press the button, the smoke soon cleared. She now knows to use the booster whenever cooking.

Pamela's kitchen boost button is locked in a depressed position and the fan only sucks for *'about thirty seconds'* before stopping (Figure 117).[151] However, she isn't aware that there is a technical issue as she *'was led to believe [….] that's what it's meant to do';* instead, she thinks its erratic functioning is just '*one of the foibles'* of the house.

> *'You don't switch it on and it stays on-- you have to keep pressing-- so literally you press it one and it goes "dzdzdzd" like that and sucks it all away'.*

Her workaround to this problem is to press the booster immediately after cooking to '*suck*' out smells, rather than switching it on before or during cooking as others do. This has led to some frustration as *'when you're doing a big meal or you're cooking, frying constantly, it's not strong enough […] it's crap.'* At these times, '*If you don't have the windows open the whole house fills with smoke and it all drifts up into the hall'*. She has learned to prevent the smoke alarm going off by opening the rooflight before starting to cook. Pamela is also disappointed that the extractor fan is not strong enough '*for the size of the house'* to remove pet smells. She blames the '*manufacturers'* and uses the windows instead:

> *'Cat litter is actually in the hall. [….] I've got the window open and it's circulating. If I didn't have the windows open I'm pretty damn sure you would smell it and it would be pretty stinky because they do get quite smelly, especially smudge, bless him.'*

This is an example of a resident trying to use the system for something it isn't really designed for. Furthermore, because she is unaware that there is a fault, she hasn't sought help, and is dissatisfied with the system. Another example of a resident misusing a technology is Carla, who struggles to stay warm during winter and has found a novel solution of using her television, in combination with closing the living room door, to warm up the space:

> *'If that TV is on, it has to be, it helps to warm it up and we keep that [door] closed as well.'*

Carla demonstrates her lack of technical knowledge by suggesting that the (PSV) ventilation hasn't been switched on by the designers: '*My hunch is that maybe there is something that they didn't switch on*'. She struggles to make sense of the PSV technology and is not able to explain how it is supposed to work, lamenting that '*these are the vents I was talking about; what they were doing, what work it does I have no clue'*. However, knowledge itself doesn't automatically translate to practice. Anthony is aware that he will need to change the filters in his MVHR unit, but is reluctant to do so until it's really necessary:

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[151] Instead of continuing for 15-20 minutes as one would expect it to do.

'I think you have to change a filter every now and again but I shall probably wait until it breaks down before I do anything.'

Institutionalised knowledge is just one element of a practice. In this case, despite having some understanding of how the system should be used, the resident's passive engagement with the technology suggests that the required maintenance may not get done.[152] Some technical knowledge about the new ventilation systems seems to be accumulated by residents as they adapt to living in their new home (e.g. from inductions, manuals, and other contacts).[153] On the other hand, it appears that use of windows may be part of older, more embodied knowledge relating to myths and past experiences.

6.4. Engagements: Providing a thermally comfortable, secure and hygienic home

Living in a safe and comfortable home is a goal for all residents. The interviews reveal a selection of activities which relate to this goal, many of which involve interactions with ventilation components; here, it appears that ventilation is part of a wider bundle of 'homemaking' practices. As well as thermal comfort (2.1.3), residents seek visual, auditory and olfactory comfort, and a feeling of safety and security at home.

6.4.1. Thermal comfort and security

Some activities relating to thermal comfort share the physical components of the ventilation system, indicating a closeness between ventilation and thermal comfort practices. For example, Dan explains that *"it can be a bit warm first thing in the morning, because obviously you get up and you open the window'.* Also, Joy describes how on hot nights she '*would leave the window open',* using night ventilation to cool down the space. Furthermore, openings can also be used in combination with mechanical ventilation, such as portable electric fans, to lower temperatures. Fara discusses her family's bedtime routine (during warm weather) which involves putting '*the fan on about twenty minutes and then turn it off"* and then *'the windows would be open'* for the rest of the night, providing a *'nice breeze'.* This family also use the bedroom rooflights to stay comfortable at night. In one room in particular they find it a useful alternative to electric fans. The reason is that one of the children who sleeps there has a disability and another is a small baby; therefore, the family feel it is safer not to leave a fan running in that room. The grandfather, who sleeps in his own room downstairs, doesn't like fans so he doesn't use one in his room. In this household, comprising 11 members, a combination of different ventilation techniques and multiple technologies are used in an attempt to stay comfortable.

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[152] Anthony part-owns his home under a shared ownership scheme and so is responsible for maintaining the mechanical systems himself (e.g. MVHR unit and boiler).

[153] See Chapter 7 for development of these ideas.

In another more extreme example, the fan is left on all night in an attempt by residents to cool down:

> *'It just gets really, really, stuffy, and really hot, unbearable to sleep really. So, soon as you sleep you sort of start getting sweaty and you can't really sleep and then the fan's on constantly.' [Sabeen]*

Staying comfortable is usually prioritised over the cost of heating or environmental concerns, although the cost of running MVHR is questioned by one resident:

> *'I've no idea what the running cost of this is. If I found out it was ten pounds a week I'd probably switch it off during the summer.' [Anthony]*

Only two interviewees refer to actively avoiding opening doors and windows while the heating is on; For example, Dan explains how he *'won't leave the heating choking away with the door open [….] I turn everything off'.* Nonetheless, keeping the household and the dwelling's contents safe is considered important enough to take precedence over thermal comfort. Several residents say that they always close windows when they go out; for example Pamela states that '*if we're out [….] windows are always shut; they're all shut'*. On the other hand, Sarah leaves upstairs windows open, but makes sure the downstairs ones are closed, when going out. Evidently, the level of concern about intruders varies between households. At Case B varying perceptions of safety and fear guide window opening. Perhaps understandably, Dan, who lives in a ground floor flat, is *'a bit conscious about leaving windows open when I'm not here*' even though he insists that '*it's a nice area, don't get any trouble'.* However, out of principle, he's always kept windows closed when going out:

> *'Never have done. Wherever I've lived I've never left the windows open when I'm not in.'*

Despite living in the second floor flat directly above Steve, Luke will not leave the window open when he goes out, whilst Steve does it every day, explaining how '*even when I goes to work I leaves that window open like that'*. Luke believes that *'it's stupid'* to leave windows open when going out, adding that *'even at two storeys someone could get in couldn't they?'* His is one of the dwellings which is most prone to overheating; it may be that this could be alleviated through more frequent ventilation. For Steve, privacy is more of a concern than safety; he keeps the curtains closed so that people cannot see into his home:

> *'I leaves the curtains drawn. I don't want, seeing my pants, do you know what I mean? I don't like the idea, I mean, open my curtains, it's rude. You don't want people seeing you in bed.'*

Finally, Maria uses the curtains to keep out light so that '*we can sleep a little bit longer without waking up',* this indicates how windows and curtains are caught up in 'bundles' of activities relating to different comfort needs.

Individual thermal comfort preferences can be negotiated through ventilation. For example, Pamela's son likes to leave his bedroom windows '*open all the time'* because he '*likes fresh air* *running through the house, well, running through his room'.* Similarly, Sarah's nephew leaves his bedroom windows '*wide, wide, open in summer and winter'* because he '*like[s] cold'*. Windows enable members of the household to adjust the temperature of their immediate environment without having to interact with the heating technology, to which they may not have access. In cases where two (or more) occupants share a bedroom, night time window-opening practices are negotiated to suit different comfort needs. For example, Karen, who has a bad back, keeps the window on her side of the bed closed as she sleeps with her back to it, while her husband, on the other side, can leave his own window open without causing her discomfort. This arrangement relies on the physical layout of the spaces as well as social relationships.

Varying use of windows reflects not only the individual thermal comfort requirements, but also points towards stratification of temperatures across some dwellings. Carla explains how temperatures vary across her house, so it can be simultaneously cold downstairs, and too hot upstairs.

> *'If it's the night I will come downstairs and turn it down so anybody sitting downstairs will not be able to stay downstairs; they will have to come upstairs.'*

This causes problems at night and leads to arguments with her husband; he works late and feels cold when he comes home, but cannot turn the heating on or his wife wakes up with a dry throat. At the same time her son is upstairs suffering from heat rash:

> *'He has to keep the window opened. [….] For him to able to sleep. Yeah because it's too hot here. [….] Every night he has to do that and he's not wearing pyjamas to sleep because it's too hot.'*

Her solution for coping with this is to turn off the heating in her room and using a heavier duvet instead; however her son's discomfort remains. Perhaps as household size grows, it becomes harder and harder to please everyone.

6.4.2. Hygiene: Maintaining a clean and fresh home

Keeping the home fresh and free from smells is also important to residents. At Cases A and B many residents use booster switches when cooking to remove smoke, steam and smells. While some people use their switch every time they cook, others prefer to open windows when carrying out routine food preparation, and only press the booster occasionally, such as when cooking a particularly heavy meal. For example, Paul states that '*if it's really heavy cooking or I'm burning something then I tend to switch it on, but otherwise I don't bother*', while Steve points out that '*it just depends what you're cooking; if you're boiling spuds and that you get a lot of steam off the bag don't you?'* On the other hand, Sabeen explains that whenever '*I start cooking I'll switch it on'*. Dan also uses the booster regularly, as there is no window in his kitchen:

> *'I use it every time I cook yeah. Just for the sole reason you haven't got a window in there. It's a bit, you know, saves your smells.'*

Dan adds that '*I keep that* [living room] *door shut so you don't get it going round the whole flat, the smell.'* Here, the spread of smells and other pollutants within the dwellings is explicitly connected to the layout of the space.[154] In some properties, open plan living arrangements are not felt to be compatible with a family's cooking practices. For example, Sabeen would prefer a separate kitchen and living area as she finds that the smell of cooking *'embeds in the sofas'*. Another resident who appreciates the separation of kitchen and living room is Carla, for whom '*closing the door'* and being able to *'stay in a particular place'* is considered a *'luxury'*. External smells may also cause discomfort and need to be removed. For example, Betty uses the booster to remove the smell of her neighbour's cooking which she believes is entering her home.

> *'When she's cooking downstairs I get her meal coming through there […] I don't know what she cooks but it's a funny smell. Yeah, but I can smell it, so I put my booster on and it goes off out again.'*

Betty is the only resident who explicitly states that she doesn't need to open windows thanks to her ventilation system. As an older person, who lives alone and who doesn't cook much, the extraction rate seems to be sufficient for her needs. As well as kitchens and cooking, bathrooms and pets were also discussed in relation to removing smells by opening windows. For example, Pamela explains that the bathroom window was temporarily open at the time of the interview, '*because somebody had done a crap',* and that the downstairs windows are generally '*open a little crack anyway just because it gets a bit doggy smelly',* thanks to their elderly pet dog. The homes at Case C do not have booster switches or mechanical kitchen extracts. For Joy, opening the kitchen door and the window while cooking is an effective way to dilute pollutants and smells and to bring in fresh air:

> *'The kitchen has got a window so like if I'm cooking, I open the door, I open the window, so at least the cooking fumes will go out and the fresh air will come in.'*

However, during summer this is insufficient for Maria, who also uses an electric fan while cooking and is considering purchasing a mechanical cooker hood.[155] In the meantime a closed door with an open window seems to be an acceptable workaround.

> *'We have a lot of cooking and we have to open the window and close the kitchen door […] because we don't have the extractor.'*

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[154] See typical floor plans in section 5.1, which show the open plan kitchen/living room arrangement at Case B (Figure 36), and the separation between kitchen and living areas at Case C (Figure 39). At Case A, the layout varies across the site with some open plan units and some with separate kitchens.

[155] The impact of a cooker hood on the PSV system is unclear but there may be a risk that air is pulled down the kitchen stack instead of up and out at roof level.

Steam is released in bathrooms as a by-product of people's showering and bathing activities. Residents carry out various ventilation activities to remove this steam so that '*everything come back to normal'* [Joy]. For example, in Sabeen's house, where the children are still young '*the doors are normally open'* whenever showering takes place. However, as children grow up and require more privacy and personal space this many no longer happen. Joy lives with her teenage and adult children and explains that, '*when anyone finish having their bath, we just leave the door open'.* In this house there is no window in the main bathroom and the resident feels that the PSV extract is insufficient to clear the air after bathing. Although the core component of the ventilation activity remains the same in both houses (opening and closing the bathroom door), this example demonstrates how elements of a practice may evolve as personal circumstances change.

Anthony uses the booster switch *'for half an hour'* every day, after showering, to remove steam. This particular routine was only encountered once, and is perhaps facilitated by the fact that Anthony and his wife live in a small flat where the bathroom is close enough to the kitchen (where the booster switch is located) for this to be practical. Other residents open windows after showering or using the bathroom, either to dilute smells or moisture. Steve has developed a succession of steps which in combination allow air to return to 'normal' after showering. He leaves both the bathroom door and his bedroom window open so that moisture is diluted with external air. He explains his need to do this in terms of his preference for hot showers.

> *'When I'm having a shower and that, I like it hot, anyway, and when I finish I just leaves the door open and my bedroom door. And with the window open the air just gets in there and makes it back to normal you know what I mean, gets the condensation out then, the steam out.'*

6.5. Ventilation technologies in practice

6.5.1. A wider definition of ventilation 'technology'

Gram-Hanssen (2011) defines the final component of a practice as 'technologies': the material artefacts or objects with which daily life is performed.[156] The examples presented in the previous sections highlight the challenge of investigating ventilation technologies in isolation, as the activities relating to them are so interconnected with other parts of the socio-technical arrangement.[157] The analysis also indicates how ventilation activities such as opening windows and doors, or pressing booster switches, are not definitive components of a universal 'ventilation practice', but bundles of activities which constitute multiple and related day-to-day practices, such as washing, cleaning, and heating.

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[156] This relates to Schatzki's concept of 'entities' (Table 14, p.75) which hang together with practices in 'arrangements'.

[157] It is worth emphasising that many of the examples presented in the previous three sections could have been included under multiple headings.

This chapter has shown how residents engage with a wide range of technological components to ventilate their homes, from low-tech mechanical devices such as windows and trickle vents, to complex and electronically controlled configurations of ductwork, fans and filters, such as the MVHR system, which simultaneously occupies all the rooms in a property. This conceptualisation of the ventilation system is much more complex than that represented by the simplified ventilation diagrams commonly used to represent domestic ventilation in the technical literature (see 2.1.5). It is also very different from the simplistic description of systems in operation and maintenance manuals provided for residents (see 7.2). Typically, some of the key devices, such as windows, doors, rooflights and poles, are excluded from conventional descriptions of whole house ventilation (WHV).

This exploration of ventilation routines indicates that individuals may not be using technologies according to the design intent. Instead, people are finding their own ways to cope with their ventilation systems, despite certain struggles, by using alternative or additional technological devices such as windows (during winter) and fans. For example, Ali spoke about how his family had adapted their routines in their new home, yet at the same time he was recreating scenes from his own childhood by opening the children's bedroom windows each morning, effectively supplementing the WHV with window-use. This demonstrates how the embodied habits, meanings, and cultural myths of the practitioner help a practice hang together.

At all three case studies, windows are an important part of both summer and winter domestic ventilation activities. Despite the presence of alternative ventilation technologies, windows remain part of daily routines and deeply embedded cultural myths about health and homeliness. Window opening is an action which is fitted around other routine daily tasks such as sleeping, working, going to school and caring for family members such as children and pets. It is flexible, intuitive and tightly clustered within a range of homemaking projects, or using Schatzki's terminology, as 'bundles of activities'. The position of newer and unfamiliar technologies within the practice appears 'looser' with less frequent interactions. Furthermore, residents may have some caution about incorporating the unknown into their daily lives until a greater institutionalised knowledge around certain technologies and components becomes more widespread.

At Case C, windows are caught up in cooking activities as families struggle to stay cool in their south-west facing kitchen and dining areas (Figure 38 and Figure 39, p.128-129). For example, Carla's *'kitchen window's always open'* when she's cooking meals for her large family. She explains how she *'used to love cooking and trying different recipes'* but that since living in the current property, which is very prone to overheating during summer, this had changed. It appears that she has tried to maintain her previous cooking activities, but despite adapting her use of windows, and using a freestanding fan to try to improve conditions, her cooking routine has changed in the new dwelling, so that she no longer cooks as much as she used to:

'I dread it. So what we tends to do is open the window and cook less [….] and then I think last summer I had to bring in the fan, the standing fan too. [Carla]

As well as routine opening and closing, several residents spoke about certain windows being open at all times throughout the year. The explanations for this range from differing comfort preferences between family members to the removal of smells emitted from pets. As a technology, windows are both simple to use and extremely versatile. They also offer an immediate connection to the outside world; for example, during her interview, Sabeen mentions that '*it was raining so I haven't opened any* [windows] *downstairs'*. This demonstrates how a natural phenomenon, such as inclement weather, can influence deviations from a routine.

Another technology which is incorporated into the ventilation practice bundles is the trickle vent. Interaction with this component seems to be straightforward for residents, who can *'just press'* the cover to slide it open or closed [Carla]. Trickle vents are also convenient as they enable residents to ventilate a space while leaving the windows closed, which provides a sense of safety and security. Generally, residents seem to enjoy having this extra level of control, exemplified by Joy describing her experience of living with trickle vents for the first time as *'Lovely. Nice. Good.'*

On the other hand, rooflights seem more problematic. Several residents have struggled to adopt night ventilation using the rooflights as a routine activity, owing to various constraints such as rain and insects. Instead, some residents are supplementing their ventilation using electric fans. This is a technology which was not part of the original design of the dwellings, and which must consume energy to function, as well as taking up valuable space in the home. Perhaps it is the portable and therefore flexible nature of electric fans that makes them so appealing in these homes, where thermal comfort and ventilation are not entirely satisfactory, allowing residents the opportunity to adapt their spaces to their needs. For example, Joy transports her fan around the house as required: '*when it's too hot I can take it upstairs'*. Despite having access to rooflights, Karen explained how they were considering purchasing an air-conditioning unit, to mitigate overheating, as their current combination of opening windows and doors and using fans is not able to provide a comfortable environment:

'Have you seen those new air conditioning units that Dyson are doing that are meant to circulate the air depending on the temperature in the house? So we're going to have a look at seeing if we can have one of those for the summer because it is so hot.'

Overheating during summertime is a concern at all three cases, something which was not experienced by many residents in their previous homes, where cold and damp were more prevalent problems. During periods of overheating a combination of doors and windows is used to cool down the internal spaces. Where this combination of actions is still insufficient to provide comfortable conditions, residents have resorted to the use of fans. The majority of residents were found to be using electric fans in their homes to stay cool in situations where various constraints are preventing natural ventilative cooling (see 5.3.2). The fans are mainly used in living areas and bedrooms. In the larger homes, multiple fans are used to achieve comfort. For example, Fara says that '*we have lots of fans, one for every room basically.'* In a few cases, freestanding air conditioning units are used too, in addition to windows, doors and fans:

> *'Summer it is the air conditioning unit that I bring downstairs and we've got a fan in every room [….]. It is literally just a case of having all the windows and doors open in the summer. […] And the air conditioning on or fans.' [Pamela]*

Perhaps the most extreme case of overheating in this study was observed in Luke's flat. He keeps an electric floor fan behind the sofa for use when it gets *'really hot'* during summer, which he uses *'all over'* the flat and in combination with open doors, closed curtains and '*no clothes'*. Despite these precautions, there were some occasions when Luke, a young and seemingly healthy man, felt so hot that he resorted to leaving the flat to escape the heat.

> *'In the summer when it got really hot [….] Yeah all over. Yeah like sitting there, no clothes, all the doors open, curtains shut, fan on, really hot. [….] Couple of times I had to leave the flat to get away from this.'*

This resident is unusual as he was one of only two people, across all three cases, to mention using curtains in relation to thermal comfort. At Case C, Sarah has successfully incorporated curtains into her summertime cooling routine. She explains her early experience of her new dwelling as '*when I first moved here I didn't have no nets and stood in the passage and thought "ooh it's hot here" and I realised it's a sun, yeah, and it wasn't that hot [laughs] it wasn't that hot but it felt really warm in the house'*. Now, during summer '*providing you've got the curtains up [….] the place is quite cool'*. However, she adds that '*if I didn't have curtains I think it would be like a greenhouse'.* On the other hand, despite closing his curtains, Luke has occasionally had to leave his flat to escape the heat. Evidently, in this dwelling, the use of certain technologies or artefacts is not in itself sufficient to prevent overheating. Despite the familiarity and intuitiveness of interacting with windows, the shading and cooling potential of curtains appears underexploited by these residents. Instead, use of curtains seems to be restricted to visual comfort, in relation to watching television and looking at computer screens. For example, Karen explains how '*when the sun comes through they can't see the telly, so I have to say that it probably is done during the summer but it's more for the TV than the air'*. Steve describes a situation where he experiences a conflict between his enjoyment of sunshine and his routine use of technologies:

> *'Sometimes the sun's coming in at that angle, it's on the telly or on my computer, yeah I would close them up then; but I likes to see the sun coming in, it makes you feel happy doesn't it? Makes you feel fresh'.*

In this example the combination of time of year and time of day creating the conditions for sun at a particular angle coincides with the time Steve likes to watch TV and relax (after work). This socio-technical arrangement, which also encompasses the orientation and layout of the flat, demonstrates how technologies are dynamically related through a range of practices which form the backdrop of domestic life.

In another example, Sabeen discusses how, as they do not have a tumble dryer, *'during the winter times we tend to sort of, don't have time to go to a launderette. We tend to just dry them [clothes] out on the heaters and the heating is on when they're on and then it's off and as it's quite warm, like the temperature say for example is set for 24.'* Here, other technologies (a washing machine, a boiler and the radiators) are part of the wintertime laundry routine. Drying laundry involves releasing moisture into the air, so although these technologies are not part of the narrow definition of ventilation, this activity is also connected to the ventilation of this dwelling, and if a ventilation system isn't designed to cope with this moisture release, problems may ensue. However*,* while daily habits are permanent, or at least strongly rooted embodies habits, it is possible that seasonal routines are less fixed and perhaps more malleable to change.

6.5.2. Chapter summary

This chapter has explored the wide range of activities which make up ventilation practices. Gram-Hanssen's framework has provided a useful set of categories with which to unravel some of the complexity of human action. Although reference to the four elements of practice helps structure a detailed investigation of people's lifestyles, the practices themselves do not fit neatly into compartments. Instead, they are dynamically connected clusters of embodied routines, conventions, meanings and objects. This interconnectedness is neatly exemplified in Sarah's observation on windows and security:

> *'Because as you go out the door, you look back and, yeah, you know to shut the windows.'*

This chapter has presented several examples of how activities may be evolving and changing as people adapt to their new homes. This shows how practices might not be fixed sequences of activities but instead dynamic and liable to change. There were certain events which took place when residents become momentarily more aware of their ventilation systems; perhaps these could be exploited to encourage the formation of different activity bundles and practices relating to ventilation. This idea of 'disruptions' offering potential for change is discussed in the next chapter.

Chapter 7: Disruptions for change

7.1. Introduction

7.1.1. Aim and structure of chapter

The previous chapter characterised ventilation practices as an actualisation of the four elements of practice: embodied know-how, institutionalised knowledge, engagements and technologies. Ventilation practices were found to comprise a loosely clustered bundle of activities, taking place across space and time (within the prefigured physical arrangement presented in Chapter 5), and often performed by several individuals within a single dwelling. These activities can relate to a variety of routinised household tasks such as cooking and washing, as well as caring for family members by providing a safe and comfortable home. This chapter investigates the ways that ventilation practices may change as residents adapt to living in their new home. The aim is to reveal ways in which more energy efficient bundles of ventilation activities could be encouraged to form.

Certain components of domestic ventilation systems may become hidden from view and are not something residents are particularly aware of while going about their daily routines (5.4.2). However, some moments were observed where the technologies became temporarily more visible. These moments often occurred around interactions between residents, and the professionals involved in designing, constructing and managing their homes. These interactions are conceptualised as ‘disruptions’, where residents’ awareness of otherwise ‘hidden’ ventilation components is temporarily raised. At these moments, it seems that the dynamic relationship between the four elements described in the previous chapter adjusts, providing an opportunity for new practices to form and for older practices to recede.

This chapter explores how such events may be leveraged to enable residents to develop more sustainable ventilation practices. Section 7.2 argues that the format and timing of formal handover procedures are not effective in enabling new, resource-efficient ventilation practices to develop. Instead, as discussed in 7.3 and 7.4, opportunities for engagement with residents of RSL-managed properties exist at various points after homes are occupied, including during the handover, snagging, defects liability period, as part of a post occupancy evaluation (POE) project and during routine maintenance and ongoing aftercare.

7.1.2. Handover as a practice-arrangement bundle

At the three case studies the client[158] is not the end user of the building; consequently, the handover[159] comprises two phases. Firstly, the contractor transfers the building to the registered

[158] In this thesis ‘client’ refers to the individual or group of stakeholders who commission and are funding the development project (e.g. a developer, housebuilder or RSL).

social landlord (RSL), and secondly, the RSL hands over the empty dwelling to the tenant. The role of the architect at this stage depends on the building contract. At Case B there was very little involvement by either architect during the handover and post occupancy stages as the contractor took over all responsibility for the delivery of the project; on the other hand, the architects at Cases A and C had more opportunities to stay involved in the project beyond practical completion (see 5.2).

Handover comprises a bundle of practices and arrangements between several groups, including the designers and constructors of a building, its owners and its occupants, as well as regulators and building control bodies. The configuration of this bundle may make it easier (enablement) or harder (constraint) for the occupants to adapt to living in their dwellings. At all three cases, the handover from the RSL to the tenants comprises a face-to-face 'induction', as well as the provision of an operation and maintenance manual (O&M).[160]

Because tenants are not involved in the handover from the contractor to the RSL, the O&M manual offers a unique point of contact between the building designers and the resident. The whole or part of the O&M manuals that were provided at each case were uncovered during the research.[161] The focus of the manuals is on providing technical information about the fixed services within the dwelling. This could be interpreted as part of the presentation of the 'institutionalised knowledge' element of practice. However, the data indicate that residents are not making use of this artefact; a more 'enabling' handover could target multiple elements of practice. For example, at Case B Luke says that *'I've opened it [laughs] […..] It's just about-- don't know actually [laughs]*'. For Paul, the *'welcome book [….] wasn't particularly helpful'*; he then admits that he hasn't dedicated much time to reading it:

> *'It might have been on page nine-hundred and seventy three but you don't do you?''*

---

[159] According to the Architect's Job Book, '*the Handover Strategy includes the requirements for phased handovers, commissioning, training of staff or other factors crucial to the successful occupation of a building'* (RIBA, 2013a). Handover occurs when the practical completion certificate is issued, by which point the contractor is expected to have overseen the commissioning and testing of the fixed services and prepared the operating and maintenance manual for the building users. At the handover meeting, the '*operating manual, keys, "as constructed" information, details of maintenance arrangements and Health and Safety file*' are all handed over to the client, who then takes ownership of the building (RIBA, 2013a)

[160] Since 2002 it has been a requirement of ADL to provide *'to the owner sufficient information about the building, the fixed building services and their maintenance requirements so that the building can be operated in such a manner as to use no more fuel and power than is reasonable in the circumstances'*. The quoted wording has remained unchanged since the 2006 edition (ODPM, 2006, p.5, HM Government, 2010c, p.5, HM Government, 2013a, p.25). Furthermore, the Code for Sustainable Homes requires that a 'Home User Guide' is provided that '*contains the necessary details about the everyday use of the home in a form that is easy for the intended users to understand'* and awards three credits for its inclusion (DCLG, 2008, p.54).

[161] The sections relating to ventilation were photographed and are reproduced in Appendix D.

At Case C, Carla remembers receiving an information booklet which explained the *'idea of the building'* and some of its *'eco-friendly'* features.[162] However, she appears disengaged with this document, as the only specific piece of information she recalls is that they must not cut the tree in the garden and that it says *'no that bla bla bla touching'.* It appears that residents may be rejecting the O&M manual. The next section questions the effectiveness of the handover process in enabling efficient use of the building, by discussing its format and timing.

7.2. Current handover not working

7.2.1. Format of the operation and maintenance manual

Contrary to architect Christopher's assumption that *'we provide tenants information and people don't read it',* several residents have made some attempt to engage with and read the manual, as discussed below. Their experiences reveal that they are struggling to engage with the current handover process. For example, at Case B, Anthony refers to the booklet as '*very brief'*; he is disappointed that he was unable to find information about the running cost of his MVHR (6.3.1). On the other hand, at Case A, even though *'everything was there'*, Karen felt that the manual was '*so complicated'* and that she would have preferred *'just an A4 piece of paper [.....] whereas we had a book'*. Sarah also suggests that she found the information confusing and unhelpful, staying that '*I thought it was a bit technical [.....] I'd like to have some more layman's term information*.'

Dan, who works in building maintenance, is one of two residents interviewed at Case B who had read the manual and was able to recall some technical details about the ventilation in his home. He explains that the *'booklet'* described *'how the ventilation system worked with the going through from the ceilings, going into the main box and then circulating the air through and then sending it back through the same, you know, same vents. Then that it's a permanent current [.....] you can't turn it off'*. However, not all the information he recalls is correct. He mentions that '*you can adjust the vents because they're on a screw adjustor. So if you want them further open, you can't obviously close them off, but you can open them further just to let the air circulate a bit better'*. This is in direct contradiction to the instructions in the manual and could potentially unbalance the system and harm its performance (p.2, Figure 204):

> *'Do not disturb or adjust these ceiling terminals, they have been set to give the correct amount of ventilation for the property'* [O&M manual, Case B]

[162] According to the previous research carried out at this case, residents were given an information booklet describing the aspirations of the project and its sustainable features, as well as providing advice to residents about energy labelling of products. The booklet also references the appropriate manuals for each of the systems in place, although detailed operating instructions were not provided (Anon., 2009).

This example demonstrates how a misinterpretation of technical instructions may constrain or impede residents' adaptation to the new ventilation system. Here, the disparity between his know-how and institutionalised knowledge hinders his ability to engage with the ventilation technology.

Although Fara describes the manual as *'really good'* and claims that she and her family *'read it all'*, this is somewhat doubtful. During the interview Fara acted as translator as her parents spoke very little English. The eldest of the eight children, she would have been only around 12 years old at the time when they moved in; the document isn't designed for children and Fara may not have understood all the information provided (see Figure 192 to Figure 195 in the Appendix, p.356). There are several other families from diverse ethnic and cultural backgrounds at this case who may have experienced similar challenges.

Steve also has difficulty understanding the content of his manual as he is severely dyslexic and struggles with basic reading and writing tasks. Consequently, he relies on his stepdaughter and brother, who both live locally, to help him read letters and deal with routine administrative tasks such as paying bills:

> *'I'm not a one to sit down and read if I'm-- and I ain't a brilliant reader. […..] If a letter comes I can read enough to know if I need help with it. […..] Sometimes I read words but it's understanding them as well. […..] It's like at work [….] they give you all these letters, they just bung that in there; no one thinks that you're on your own or you're dyslexic. They just think that you can read and it's embarrassing telling everyone all the time. I don't like everyone knowing'.*

In these examples a language barrier and learning disability constrain residents' engagement with the manual in its current form.

The information provided in each manual varies between cases. At Case B, despite its thickness, only four pages relate specifically to ventilation, in the form of the MVHR unit manufacturer's product manual (Figure 54). This provides generic information about five different products from the same manufacturer and mentions certain features (moisture sensors, the '*manual summer override switch'* and trickle ventilators) which are not present in these residents' installations. Borrowing Gram-Hanssen's practice framework, this introduces 'institutionalised knowledge' and 'technologies' which are irrelevant at this case; such information may lead to confusion among residents.

Figure 54: O&M manual at MVHR site[163]

The manual includes a few sentences about why controlled ventilation is important in airtight homes and explains that *'heat is reclaimed from the extracted air and used to preheat incoming fresh air by a "heat exchanger" which is built into the central ventilation unit'* (Figure 204). Two diagrams are used to illustrate this. Figure 55 shows a diagram which is unlabelled and unlikely to be informative for a non-expert reader. Although labelled, Figure 56 is also very diagrammatic and only illustrates a generic schematic rather than the actual installation for the dwelling. Therefore important information about how the ventilation practice might actually be performed in relation to this technology is missing: for example, how to identify and locate the booster switch, where the filters are located, how to change them and where to purchase replacements.

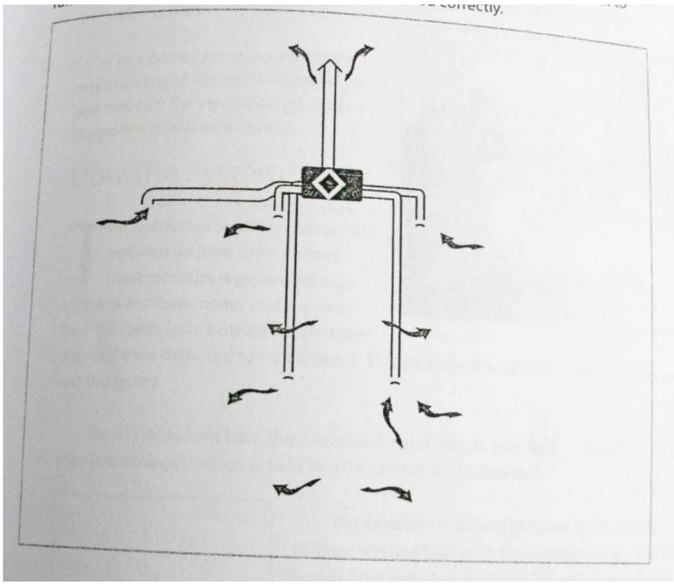


Figure 55: Illustration from Titon user guide, p.1 (full image in Figure 203, Appendix)[164]

[163] Name of project and developer have been covered for anonymity.
[164] It appears that the rest of this figure was lost at some point during the photocopying and reproduction of the manual (by the person who compiled it: the author's reproduction accurately

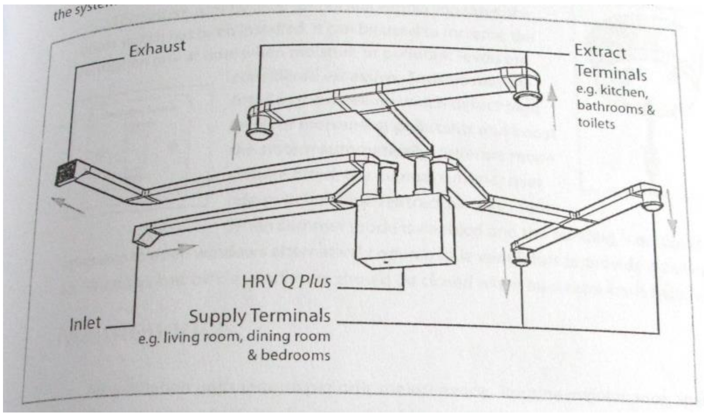


Figure 56: Illustration from Titon user guide, p.3 (full image in Figure 204, Appendix)

At this case, a second piece of written information is provided to tenants[165] in the form of the RSL's "New Homes Manual". The ventilation section focuses on more practical guidance for residents to manage '*drying out'*, *'condensation'* and '*shrinkage cracks',* such as *'leaving windows and cupboards slightly ajar'* and not *'stacking things against the walls in cupboards'* to prevent moisture build up (Figure 208). However, because this is another generic document, this time aimed at all new tenants of that particular RSL, there is no reference to the MVHR.

The manual provided at Case C combines generic product manuals with information relating to the specific dwellings. A mistake was observed in the section titled *'extract fans'* which states that *'your home is fitted with Passivent positive pressure air system [……]. It is advisable to periodically clean the outlet with a vacuum nozzle. Note: always ensure the fan is turned off on the circuit board when attempting this'* (Figure 210, Appendix). The final sentence is misleading as there are no electrical components which could be switched off in this ventilation arrangement. It also contradicts the RSL's statement that *'it certainly needs to be explained to them that there's no fan, there's nothing mechanical, and it's all going to be natural'* [Michael]. This may also explain why Carla, who appeared '*disenchanted*' with her system was so adamant that her ventilation needed to be switched on (6.3.3) (Behar and Chiu, 2013).

The tenants' manual at Case A is a smaller document that has been written specifically for this development, by the architect and a past employee of the RSL. It includes one short paragraph about the ventilation, reproduced below:

> *'Your house is fitted with a controlled ventilation system which provides fresh air continuously day and night. The system extracts moist air from the kitchen, shower room and bathroom. The other rooms, living room and bedroom have fresh air inlets in the wall. The system is controlled*

---

depicts the information provided to at least one resident). Figure 207 shows the same image in the 2011 version of the product manual, which depicts a section of a house behind the AHU diagram. However, there are still no labels.

[165] That is, Dan, Luke, Steve and Paul. Betty and Anthony part own their flats and, according to housing officer Janet, would not have received this document.

automatically by humidity sensitive valves so that the system extracts more air if you are cooking or having a bath or shower. It also lets in less fresh air if a room is unoccupied. There is a switch in the kitchen, which allows you to boost the extract rate in the kitchen to remove cooking smells. The inlets and outlets should be kept clean and unobstructed' (Figure 194).

This is an accurate description of the different components of this particular ventilation system. However, noticeably absent is any reference to the location of the air handling unit (AHU) in the loft space and to the need to clean or replace filters on a regular basis.[166] Also missing from all three manuals is any reference to using windows for routine ventilation.[167] This is interesting because windows certainly form part of the complex and interconnected physical ventilation arrangement that was defined in Chapter 5, and were found to be an integral component for domestic ventilation through reproduction of deeply embodied daily routines (Chapter 6). The absence of windows in the manual at Case B may be because they are not part of the fixed building service product which is manufactured by this particular supplier and therefore are not deemed to be part of their system. However, by omitting this information from the manual, the importance of removing moisture from spaces which do not have windows, such as the bathroom in these flats, is not explicitly mentioned. The previous example raises the question of what information should be included in the handover documentation so that residents have a chance to benefit from these procedures, which are embedded in the building regulations and sustainability frameworks. This is discussed further in section 7.4.

7.2.2. Timing of the delivery

The O&M manual is often delivered to residents during the handover induction, which usually takes place on the day that tenants receive the keys to their new home. For example, Karen remembers being given a *'welcome pack […..] literally as we moved in'*. Housing officer Janet explains that the main purpose of the induction is to enable the residents to make *'informed decisions about what to do and who to contact'* if there is a problem or emergency. Because potential residents were found to be more interested in taking measurements or photos of the dwelling, a checklist was introduced, by the RSL, to ensure that all the required topics were discussed at the viewing and sign up stage (Figure 57).

Perhaps unsurprisingly, it appears that as residents view a flat they are more concerned with imagining their future lives there, rather than listening to practical information or being told the rules. At Case A, housing officer Helen suspects that during the handover induction *'people are*

[166] As discussed in 5.4.2, several of the residents were unaware of the presence of the MEV unit for several years and the RSL were unaware of the maintenance requirement until revisiting the properties as part of the Green Doctor initiative.

[167] At Case B, the New Homes manual mentions leaving windows 'slightly ajar' but this is in relation to drying out a new property and not day-to-day ventilation. At Case C, the manual mentions windows as the location of trickle vents and, later, as a potential location for the formation of condensation. However, the actual act of opening and closing windows is not referred to.

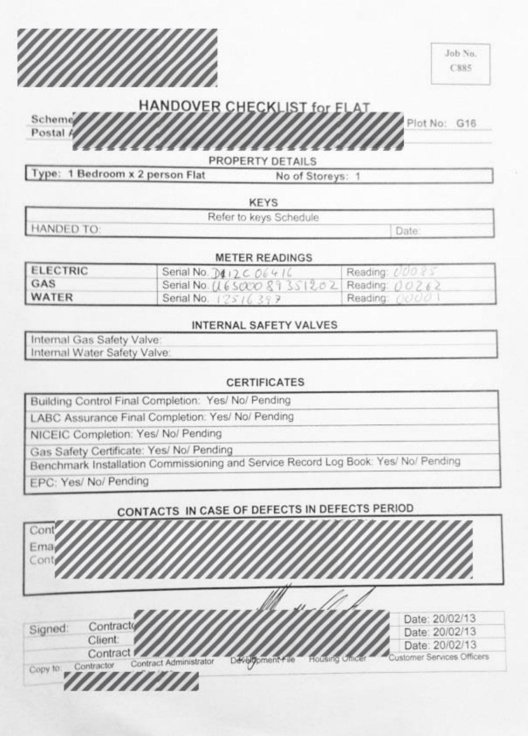
going round thinking "will my yellow carpet fit in this room?" And someone's going "ble ble ble ble" about the ventilation system'. Janet sympathises with the residents saying *'I'd be the same "I just want my keys. I want to move in and I want to be left alone [laughs] just to get on with my life really"'*. This may explain why Sarah felt that she was *'rushed through'* the induction with her housing officer and '*didn't quite absorb it'*.

Janet describes the process which she goes through with each new tenant. When potential tenants view a new property they are shown the utility meters, and told about *'bin days', 'what they're allowed to do in the communal areas'* and the terms of their *'probationary tenancies'*.[168] Following the initial viewings, the tenants visit the office to *'sign up'*. Here, they are shown a DVD about the RSL and then the housing officer explains the keys.[169] They then view the flat together again, this time with the *'handover checklist'* and the *'occupiers' inspection form'* (Figure 57). It is at this point that the O&M manual is presented to the new tenant, alongside the aforementioned New Homes Manual. However, although Janet personally hands over the manual, she is unsure how useful this really is:

> *'I just hand it to them, yeah. I don't know if they ever read it to be honest [laughs] especially as they're more interesting in just moving in and getting the keys.'*

This description demonstrates how the timing of the handover, on the day people move in, is not conducive to enabling residents to learn about their ventilation system. At this time, the O&M manual may get lost amongst the excitement and stress of moving home as well as within the other paperwork which constitutes this handover arrangement. This suggests a need to give more manageable information, at appropriate times, so that residents are not overwhelmed by the process.

[168] The requirement of this tenancy is that the housing officer visits the resident in their property after one month, six months and nine months before awarding a full contract.
[169] The keys comply with *'Secure by Design'* and therefore require specialist replacement if they are lost.



[redacted]

Job No.
C885

HANDOVER CHECKLIST for FLAT

Scheme [redacted] Plot No: G16
Postal [redacted]

PROPERTY DETAILS

Type: 1 Bedroom x 2 person Flat No of Storeys: 1

KEYS

Refer to keys Schedule
HANDED TO: Date:

METER READINGS

ELECTRIC	Serial No. D12C 06416	Reading: 00085
GAS	Serial No. U6S00089351202	Reading: 00262
WATER	Serial No. 12516397	Reading: 00001

INTERNAL SAFETY VALVES

Internal Gas Safety Valve:
Internal Water Safety Valve:

CERTIFICATES

Building Control Final Completion: Yes/ No/ Pending
LABC Assurance Final Completion: Yes/ No/ Pending
NICEIC Completion: Yes/ No/ Pending
Gas Safety Certificate: Yes/ No/ Pending
Benchmark Installation Commissioning and Service Record Log Book: Yes/ No/ Pending
EPC: Yes/ No/ Pending

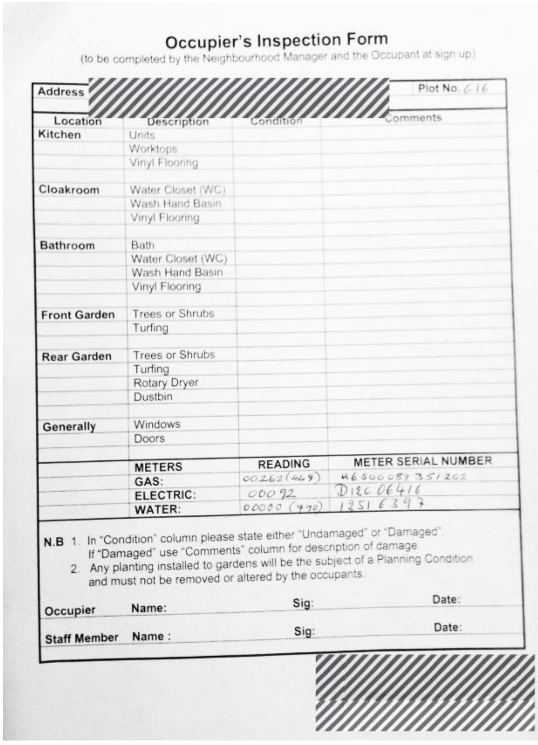
CONTACTS IN CASE OF DEFECTS IN DEFECTS PERIOD

Cont [redacted]
Ema
Cont

Signed: Contract [redacted] Date: 20/02/13
Client: Date: 20/02/13
Contract Date: 20/02/13

Copy to: Contractor Contract Administrator Development File Housing Officer Customer Services Officers

[redacted]



Occupier's Inspection Form

(to be completed by the Neighbourhood Manager and the Occupant at sign up)

Address [redacted] Plot No. G16

Location	Description	Condition	Comments
Kitchen	Units		
	Worktops		
	Vinyl Flooring		
Cloakroom	Water Closet (WC)		
	Wash Hand Basin		
	Vinyl Flooring		
Bathroom	Bath		
	Water Closet (WC)		
	Wash Hand Basin		
	Vinyl Flooring		
Front Garden	Trees or Shrubs		
	Turfing		
Rear Garden	Trees or Shrubs		
	Turfing		
	Rotary Dryer		
	Dustbin		
Generally	Windows		
	Doors		
	METERS	READING	METER SERIAL NUMBER
	GAS:	00262 (449)	U6500089351202
	ELECTRIC:	00092	D12C06416
	WATER:	00000 (790)	12516397

N.B 1. In "Condition" column please state either "Undamaged" or "Damaged".
If "Damaged" use "Comments" column for description of damage.
2. Any planting installed to gardens will be the subject of a Planning Condition and must not be removed or altered by the occupants.

Occupier Name: Sig: Date:

Staff Member Name : Sig: Date:

[redacted]

Figure 57: Handover Checklist (left) and Occupiers Inspection Form (right) at Case B

Personal circumstances may also inhibit an individual's ability to benefit from handover procedures. For example, when asked about the manual, Steve replies that '*I can't remember properly because, not being rude, just before I come here my life was a disaster'*. A series of unfortunate incidents, including the death of this father and the break-up of his relationship ('*my other half had an internet affair, nicked all my money, left me twenty-seven pence [….] she used my bank card and everything'*) meant that when he was moving home his '*head was only just clearing'* and his priority was '*trying to sort my life out'* rather than studying the technical documentation provided at handover. Compounded with his dyslexia, it is unlikely that Steve's understanding of ventilation was enhanced by his experience of the handover.

The current configuration of the handover, in terms of its composition, content and the timing of its delivery, does not appear to be conducive to recruiting practitioners to practices which would enable them to perform ventilation in an efficient way. When residents do read the manual they often find it too brief and lacking in practical information. At the same time, some residents express a preference for a shorter document; these two issues are contradictory and may be hard to reconcile. For example, Anthony explains that he read the manual *'religiously'* because he was trying to work out how to increase the temperature of water in the bath taps. This example indicates that the resident referred to the manual when he wanted to troubleshoot a specific problem, which he was unable to do. However, based on this incident, the manual's use as a tool for learning about how to incorporate a new technology into one's lifestyle remains questionable; Anthony shares the same thought when he says that despite the manual being *'as comprehensive as anything else I've previously seen before, […..] I don't think you look at* *them until you've got a problem. That's probably the issue'*. The examples discussed above suggest that the O&M manual alone cannot be relied upon to provide an appropriate induction to the new ventilation system.

As a building nears completion, several things occur simultaneously, not only on paper, as contracts are signed, certificates issued and payments made, but also in terms of the physical arrangement of a building's components, which continue to evolve as services are commissioned, defects rectified and furniture installed. Handover is also a busy period for the RSL and design team. As Douglas notes, *'they've got a million and one things to think about as they're coming up to handover [.....]. The quality of the resident manual is not always top of their list'*. Owing to financial pressures, the RSL is trying to get people into their homes as quickly as possible; as Martin puts it *'they're in the next day'*.

As people move in, their living practices collide with the physical fabric of the architecture, whose arrangement is particularly fluid at this time. For example, laundry activities which involve drying clothes inside release additional moisture into the air and may hinder drying out. A low energy building's fabric may be take longer to dry out than traditional construction, because of its airtightness and reduced permeability. Contractor Martin explains how even though they use dehumidifiers and open the windows when they can, '*it's a slow process basically and it's not completed by the time people move in'.* Alternatively, windows may be left open and the heating switched on, which wastes energy. During handover the spatial, technical and the social are intertwined in a tight web of practices and arrangements. Untangling this bundle may offer opportunities to improve the handover experience to help residents use the ventilation as intended.

7.3. Learning from 'disruptions'; design team and resident interactions

7.3.1. Moving into a new home

Maria recalls being informed, during the handover, that the trickle vents have '*to be still open all the time, so it makes the air coming through the house'* and that she must not cover the ceiling extract vents '*because that's the ventilation'*. She appears to have adapted well to the PSV system and is using the trickle vents as advised. Her ability to adapt to the new environment may relate to her previous experience of a cold, damp and mouldy home, where a health visitor suggested that her young daughter's hay fever and allergies were caused by the '*big, big, mould on the ceiling and the walls'*. Her daughter's health has improved since they moved house and Maria is very satisfied with her '*nice and comfortable'* new home.

For Maria, the handover has effectively recruited her to participate in a new ventilation practice. Her previous, embodied experience of living in a damp home, as well as her understanding of the importance of providing a healthy home for her children, have enabled Maria to engage with the handover in a way that others haven't. This suggests that while the typical handover process provides only institutionalised knowledge, the other elements of a practice (know-how and engagements) may also need to be aligned to facilitate change. This resonates with the writing of Shove et al. (2012) that '*practices change when new elements are introduced or when existing elements are combined in new ways'* (p120).

Ali is also pleased with his home and had a positive experience of the handover process:

> *'They gave us an info pack. They were good in terms of that [….], spoke about the architecture, spoke about the-- in fact the architect came over as well to see how we're doing.'*

Ali refers to the architect by name and describes him as a '*lovely chap'.* This resident is very welcoming to visitors and explains how *'there were architects coming in, and people normally come and have a look at our house and we talk to people and stuff, and I can't stop talking anyway'*. Perhaps this is why his house has been used as an exemplar for the project by the design team and the RSL. Over the course of their visits Ali has acquired technical vocabulary about his home which was not used by other residents. For example, he mentions the ventilation system without being prompted and uses terms such as '*low airtightness'*, *'carbon footprint'* and *'lime render'*.

Both Maria and Ali shared a similar experience of not being able to open their rooflights until long poles were provided, enabling them to reach previously inaccessible components (see 5.3.2). Ali is unable to work owing to disability. However, he is very engaged in his local faith community and contributes voluntary work whenever he is able. Before the poles were provided, Ali found the overheating in one of the upstairs rooms so unbearable that he purchased a laptop so that he could work downstairs instead. This is an example of how an activity (work) can be constrained by the absence of a certain technology (the pole) and then a new set of activities enabled by the introduction of a different technology (the laptop). By disrupting Ali's work routine, which he values a great deal, the overheating bedroom and lack of pole provided the conditions for a new embodied routine to develop to work around the problem, aided by the purchase of a laptop.

At Cases A and C where Ali and Maria live, the same architects were involved through all stages of the design, including snagging[170] and completion;[171] therefore, they had several opportunities to visit the buildings and to address any defects, after the residents had moved in.

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[170] *Snagging* takes place as a construction project nears *Practical Completion*, a term used to describe the moment when the duties outlined in the contract have been completed, a certificate is issued and the project is handed over to the client (RIBA, 2009, RIBA, 2013b). Snagging is an unofficial term used within the construction industry to describe the process of inspecting the building, during the final weeks of construction, to identify any remedial works which need to take place prior to issue of the certificate of practical completion. Snagging is typically carried out by the architect or contract administrator.

[171] Practical completion marks the commencement of the defects liability period. This is a period, typically lasting 12 months, when the contractor can be recalled to rectify any defects which may appear.

The collaborative working relationship between members of the design team enabled the two architects to take a more flexible and involved role in the projects, despite each scheme being procured under a *Design and Build* contractual agreement, which usually excludes architects from the later stages of a construction project. For example, at Case C, the RSL evidently understood the importance of working with a connected design team when they appointed the whole design team from a project they wished to emulate (see 5.2.2), while at Case A the RSL were working with the same architect over a series of projects to develop a replicable prototype for sustainable social housing (see 5.3.1). These relationships encourage, rather than eliminate, designer involvement with building use and performance. The opportunity for residents to gain insight about the systems in their homes from interactions with the design team is usually only available to the first occupants of the dwelling (if at all). Subsequent tenants will not have such ready access to members of the design team and passing on the insights obtained during the interactions between the first generation of occupants and the design team is an interesting challenge to consider.

According to the construction professionals, defects are *'simple things'* (Martin), such as stuck doors, cracked plaster or *'making good decorations' (Christopher)*. However, something which appears trivial from a professional's point of view may be much more significant for the person who has to live with it. This is exemplified in Ali and Maria's struggles to use the rooflights until they were provided with a pole with which they could reach and open them (5.3.2).

At Case C, the contractor Martin recalls an incident on a previous project where they '*actually had to go back and put towers up and knock holes in the walls to put in air bricks',* as the M&E consultants made the assumption that *'because we're English builders [….] there would be gaps everywhere'* and had not allowed provision for air inlets in their design. The issue was discovered during a site meeting when they felt like they were *'running out of oxygen'*. By experiencing the building as occupants, however briefly, the design team were forced to challenge their design and construction assumptions. This demonstrates how a system or arrangement can only really be tested with the people in it. At Case B, neither of the architects were present at the snagging or defects inspections, as the contractor-developer were contract administrators at this stage. The construction architect's involvement in the project finished with the completion of the working drawings package and the subsequent sign off from building control. Construction architect Dominic explained that *'the only time we do go back after […] when the residents have moved in is maybe if we want to do like, sort of, photos or stuff for the brochures'*. Therefore, there was no opportunity for residents to meet the designers of their home, nor for designers to learn from visiting the occupied buildings.

7.3.2. Investigating occupied homes

Betty took part in a POE interview shortly after moving into her flat.[172] She later recalled mentioning that she could not open the living room window fully to the POE interviewer, who then showed her how to *'unhook'* the safely latch so that she can now *'open the window properly'*.[173] Betty does not remember receiving the O&M manual and insists she was given *'no written instruction whatsoever [.....] just given a bunch of keys and said "there you are take them and go"'*. However, the incident with the windows has made a lasting impression and helped her achieve comfort in her home. Her experience during the interview can be understood as a 'disruption', which provided Betty with the embodied know-how needed to override the safety latch. This enabled Betty to take part in a new ventilation activity, opening the living room windows. Betty is an older person who is unable to reach the high level window above her kitchen sink (Figure 36, floor plan (top image, p.126)). Therefore, it may be useful for her to be able to open one window wide, rather than open several just a small amount.

During his interview for this PhD research, Steve describes his daily showering and airing routine, where he opens both the bathroom and bedroom door as well as his bedroom window, to refresh the flat and dilute steam (Figure 37, floor plan; see quote on p.167). When asked whether he ever used the booster for this purpose Steve replies that he hasn't, but that he would try it that day.

> *'I'll do it today. Now you've been here I'm just going to do it and see if it does it [....]. I'll put it on full and I'll shut the door and then see if it sucks all the steam out, see how long it takes.'*

In this example, Steve is introduced to a new way of ventilating, using a component he is not familiar with, whilst participating in a piece of academic research. While Steve struggled to engage with the O&M manual and handover induction because of his limited literacy and difficult personal circumstances, this brief dialogue raised his awareness of his everyday routine and allowed him to consider alternatives. Steve lives in a small flat where the bathroom does not adjoin an external wall, so there are no openings other than the door and the MVHR extract. Steve's airing routine may be a continuation of activities developed in his previous, naturally ventilated home, where it was cold and damp with black mould and condensation on the walls. Opening the windows after showering would have been critical there, and the practice may have become embodied through regular repetition.

Several other residents at Case B also remember participating in the POE. For example, Luke recalls receiving numerous visits which probably relate to the in-depth monitoring that was

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[172] Funding for POE was obtained by the consortium responsible for the development midway through the project. It was carried out by a consultancy with support from UCL. The author of this thesis was responsible for conducting questionnaire surveys with residents but was not involved in these interviews.

[173] The safety latch prevents windows being opened wider than approximately 100mm.

carried out in his flat. He explains that someone from '*a university'* told him about the ventilation system and remembers *'something about it taking the moisture out so you don't get mould, and taking bad smells out'*. However, Dan was left confused after supposedly being told that the air extract vents are *'part of an experiment'* and that he should *'leave them alone'*. Betty remembers being told *'not to touch'* the sensors and monitoring equipment in the hallway cupboard so it's possible Dan received the same advice and has confused the handover induction with the POE visits. This demonstrates how important it is that POE research is carried out in a way that does not cause more confusion than help.

There is general agreement among all the professional informants that POE is an important and valuable process for getting a *'proactive loop feedback'* (Helen) and an *'indication of what goes well and what goes wrong'* (Eddie), and is therefore a useful tool for improving future designs. However, the potential for residents to benefit from this process too was not mentioned. For Steve and Betty, taking part in research about their home has enabled them to consider new means of ventilating, in a way that the handover inductions and operation manual could not. Rather than focusing on providing technical information and setting 'rules' for ventilating, the residents have benefitted from interventions which engage their embodied experiences of the physical environment. Instead of written instruction, Betty was physically shown how to adapt the space to her needs; by reflecting on his own routine, Steve was able to imagine an alternative way of maintaining a comfortable home.

7.3.3. Maintenance and ongoing aftercare

The opportunity to develop new ventilation practices through 'disruptions' continues even after the defects period is over and residents have settled into their new homes. At this time incidents relate to encounters with the RSL during routine maintenance or interactions between family members. For example, Sabeen recalls an experience where the strength of the booster extract in the kitchen started to deteriorate, to the point where '*whenever we used the button it wasn't like taking anything out'*. Although she suggested to her husband that the cause could be a dirty extract vent, they *'didn't really bother with it [….] just opened the window'* instead. Then, without telling her, Sabeen's husband cleaned the vent out so that the booster started working again. Once she discovered this she reverted to using the booster switch whilst cooking:

> *'And then my husband I think once, he didn't tell me, he just cleaned it. And then he said to me while I was cooking-- I said "oh if only that worked", he goes "oh it does work", I said "you never told me" [laughs] and he goes "look" and he showed me and I said "oh you" he goes "I cleaned it". So yeah we use it now.'*

This example demonstrates how a faulty or broken component inhibits a certain course of activity and may prompt residents to seek alternative strategies. Once this component was cleaned and became functional again, the residents were able to return to the previous activity, here using the booster switch while cooking. However, there is some evidence that this effect may be short-lived, as this was the second time a similar incident had happened. Sabeen mentioned that when they first moved in they also used the booster until the fan got clogged up, after which they stopped using it until they were advised the RSL that it needed to be kept clean. This suggests that a practice needs to be performed regularly and frequently or it may be forgotten or discarded, and that when people fall out of the system of knowledge they may need reminding or help to get back.

The homes at Case A were occupied for several years before the RSL realised that the MEV fan unit required an annual service (see 5.4.2). Karen, Fara and Sabeen recalled first finding out that they had this piece of technology when the RSL came to carry out maintenance for the first time. For example, Karen remembers seeing something *'like a hoover'* being used '*to clean it all out and to get the dust out'*. Although she has never been up to the loft to see the unit, Fara knows what it does as *'when the guy came to change it I saw it […..] it's really manky. Obviously it's all dirty because it's been there for a whole year filtering everything'.* The MEV units at Case A are 'hidden' in the loft, which is only accessible through a door located on the mezzanine level (Figure 52). For each of the residents, their awareness of a previously unnoticed component is raised during these events.

In these examples of RSL tenancies, the maintenance is taken care of by the landlord (see 6.3.1 where Fara remembers being advised to leave maintenance to the professionals). However, in a privately owned homes residents must organise the maintenance themselves. It may be unrealistic to expect these residents to develop the 'know-how' to participate in ventilation maintenance themselves. This is because these systems require infrequent maintenance rather than regular attention. The example of Sabeen and her husband's experience of cleaning the extract vent, as well as the habitual activities presented in Section 6.2, suggest that embodied know-how is reinforced through frequent enactments of a routine activity, and can become lost after periods of inactivity.

The RSL at Case A had launched a *Green Doctor* initiative with residents shortly before the interviews took place. The project includes making home visits *'to help tenants and communities to cut their energy and water use, reduce emissions and save on household bills'*.[174] At the time of the interview eight out of 14 houses had been visited and the long term goal is to run the programme across all of their housing stock.[175] Three of the eight households were also visited as part of this PhD research.

Sabeen and Fara describe how they have started regularly cleaning out the extract vents after being advised, during a Green Doctor visit, that doing so would improve the ventilation performance. Sabeen discusses a recent visit when Eddie and Yvonne came to her house together to do an *'inspection'* and were *'checking if everything was working'*. She refers to

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[174] As introduced in section 5.3.2 (footnote 139).

[175] Eddie explains how they are piloting the scheme at this group of homes because *'it should have meant that we had fewer issues to deal with so we could just get the process set up and running'*.

Yvonne by name and explains that *'she said [the ventilation] should be working all the time [.....] said it just takes out all the steam and then it lets in all the fresh air as well'*. She then describes how Yvonne showed her how to test if the trickle vents and *'extra boost'*, are working. To test the inlets '*you just put your hand next to it and see if there's any air coming'* and with the extract vents you *'just put paper on top of it and if the paper stays that means it's definitely working'*. Sabeen explains that these tests are required because the system *'doesn't make any noise'*. This is another example of an event where hidden components were revealed to the resident. Yvonne has found a way to make air movement visible, through the resident's sense of touch and her sight. Instead of providing written instructions or highly technical information, this intervention is successful because it engages the resident's embodied know-how and senses.

7.4. Opportunities for change: the role of RSLs as intermediaries

7.4.1. The positon of RSLs at handover

Although the handover process in its current configuration is not perfect, the discussion of 'disruptions' indicates that there may be opportunities for change. However, as well as guiding current practices in a helpful way, the handover may also cause confusion or encourage unhelpful practices to develop. For example, at Case B, housing officer Janet advises residents who report cracks in their walls '*to put their booster switch on'*.[176] Unfortunately this may exacerbate the problem as accelerating the drying process increases the likelihood of cracking.

Janet admits that she's *'never read'* the O&M manual, despite being responsible for the handover inductions. The lack of understanding of technical systems among RSLs is raised by architect Helen, who recalls visiting a property with a housing manager, whom she asked to *'explain the boiler'*. It soon transpired that *'she didn't have a clue how it worked'.* It seems unreasonable to expect residents to know how to ventilate effectively if their main point of contact with the RSL doesn't understand the system themselves.

The need to engage housing officers with issues of sustainability and usability is raised by the sustainability officer at the MEV site, who says that *'I really don't see that housing* [officer] *gives enough information when people move in.*' Many of the RSL informants were knowledgeable and enthusiastic about the whole house ventilation (WHV) systems in the homes. However, RSLs can be large organisations and, in some instances (e.g. Case C) staff are quite removed from their clients. The housing officers at Cases A and C did not participate in this research. As discussed in 4.4.1, when the housing officer at Case C was invited to take part in an interview she declined, as she rarely visited the site and did not feel able to contribute. Her equivalent at Case A was similarly reluctant to participate.

176 Cracked paintwork is a common occurrence during the drying out phase of a new home.

Housing officers are uniquely positioned in the handover arrangement. They are the group of actors responsible for conducting the handover and act as intermediaries between the design team and the end users of the technologies. Therefore, they are in a powerful position to instigate change. For example, At Case B, Janet knew most of the residents by name and frequently visited the homes. Rather than focusing on accessing every resident individually, interventions to encourage lifestyle changes from tenants could be aimed at the housing officers who can then work to engage residents directly.

At Case B, the contractor-developer explains that because they were not able to offer the *'meet the builder'* service which they provide with their privately sold properties, they conducted an *'induction with members of* [RSL]*'s team to make sure that they were made aware of how the system works, what the system needs to operate and then, so they can then pass that on, on their handover to the tenants'* (Stuart). However, neither the housing officer nor the project manager mentioned this induction during the interviews; therefore, it is unclear how well these aims, to enable RSLs to *'follow that information through to their tenants,'* are being met.

An RSL's ability to encourage change may be constrained by the extent to which housing management see themselves as responsible for helping residents live with new technologies. For example, although Douglas, the business manager at Case C, admits that *'we don't provide sufficient support for residents I think to assist them',* he then adds that *'we are their landlords, we're not their mothers'*. Furthermore, his colleague observes that they are dealing with *'complicated machines'* and that *'we're realizing more and more that* [the] *message we probably need to get across residents is "just don't touch anything, leave it"'* (Michael). This RSL have a very large housing stock and may have insufficient resources to maintain close contact with individual residents. On the other hand, POE consultant Richard, who works with smaller housing associations (e.g. Case A), mentions that '*most of the landlords [….] have been quite keen to sort of mollycoddle their tenants in these sorts of houses and look after them'*.

The example of routine maintenance of the ventilation fan unit is used to discuss the issue of responsibility further. Sustainability officer Yvonne believes that RSLs should help residents adapt their lifestyles, yet she doesn't think residents are able to carry out ventilation maintenance themselves: *'the thing is, yes, you're right, they could but they don't'*. She then also adds that:

> *'If they can't use the house or they have to-- if the house needs a certain type of behaviour which then cannot be done […..] I think we need to recognise that and help them out, even though it costs money. And it's not just because we spoil our tenants and we just say "yes" to everything they want; that's not really the point, it's just taking responsibility'.*

Her colleague Eddie also doubts whether residents can be expected to maintain the fan units themselves until the technology '*becomes more mainstream'*. He suggests that ventilation performance could be improved if cleaning the extracts became part of the *'maintenance schedule'*, though he notes that '*if you do that do we ever advance the technology in terms of […..] having it more acceptable among the users?* His concern is justified in terms of this study, where regular performance was found to be an important element in the existence of practices. If the RSL continue to carry out the maintenance on behalf of residents they may be perpetuating the existing situation and excluding residents from engaging with the technology. Thus, parts of the ventilation system remain hidden from residents. Instead of debating whether residents should be left to get along with it, or whether RSLs should be carrying out the maintenance on behalf of residents, a middle ground could be sought where RSLs acknowledge their potential to help residents, and focus on interventions which relate to all four elements of practice, by engaging embodied know-how and meanings as well as providing technical knowledge about unfamiliar systems.

7.4.2. Strategies used to help residents

Improve format and delivery of manual

Since the projects were completed, two of the RSLs have been taking steps to improve their handover procedures. Both Michael and Yvonne were working on rewriting the user guides at the time of the interview.[177] Yvonne explains that the new version of the manual has a longer ventilation section, written in *'layman terms'.* It also mentions that *'in winter there is no need to open windows'* and that the rooflight can be used to *'allow hot air to escape'* which *'is best done during cooler evening time'.* Although this version is more informative than the first, the format remains text heavy, and may be inaccessible to less literate people or non-native English speakers.

However, much of the information that informants felt that residents needed to know about WHV is missing from all the guides. For example, Janet believes residents should be told *'how to heat or ventilate their homes for the lowest cost possible,'* but the running cost of MV systems was not mentioned in any of the O&M manuals. For Christopher, residents must be aware of the importance of '*night purge ventilation for overheating'*. His description of how the ventilation works is quite different to that presented in the manual (see previous quote in 7.2.1 from Figure 194, Appendix).

> *'You have a rooflight which is operating with the stack effect so it's drawing air through the building and doing it at night so what it's doing is pulling cool air through the building at night and then you probably close the windows during the day. […..] In the morning it will be cool-ish and it will stay that way if the windows aren't open.'*

Richard suggests that residents '*should know that it should be providing enough ventilation for them with the winter for them not to need them opening windows. […..] And if they're feeling too warm they should look at turning the heating down first'*. This is only addressed in Yvonne's revised document and is not present in the information received by the residents at the time of

[177] Case A user guide is reproduced in Appendix E, Figure 196.

the research. From the RSL’s perspective, residents need to be much more aware of the need to keep the extract clean, as this is not something they are currently doing that well.

The reason important information is missing may be because the O&M manual appears to be produced in a rather haphazard way. For example, At Case B, it was compiled by the developer-contractor, Stuart, based on what he felt was *‘best for the people to be able to have in front of them without being too much and trying to just give them too much information, but enough that they can run their house’*. The guide is then checked by the RSL and the Code for Sustainable Homes (CSH) assessor ‘*to make sure they’re happy’* before being passed on to residents. At Case B, the RSL’s own “New Homes Manual” was prepared by project manager Brian and is occasionally updated when they ‘*find people coming back with questions and it’s not in there.’*

Stuart’s impression that he is doing what *‘is best for the people’* draws attention to what can happen when a technically competent individual attempts to predict what might be useful for a non-technical end user. Although he is trying to be helpful when he says ‘*I think it’s worth putting all the information in there so that if they need to get any parts they know where-- what they need’*, the guide does not appear to be as effective as he might have hoped. As he says, ‘*it’s one of those thick documents you look at and you think “well I haven’t got time to read all that”’* and that ‘*maybe if something goes wrong somebody might pick it up and-- if they can remember where they put it’*.

The reliance on a contractor, or subcontractor, to prepare the O&M manual may be limiting the potential of the architect to communicate their design intent to the residents. At Case A, the original manual was prepared by Christopher, but since then the RSL *‘took over that role’*. Christopher was disappointed by this and thinks *‘that was a bit off really’*. Architects are potentially well placed to prepare this kind of information as they are experienced in communicating visually, and, at least in these exemplar low energy housing schemes, are the person pushing the sustainability agenda and making decisions on how this is materialised in the final design. Unfortunately, this is not something they typically get involved in. For example, Dominic believes that the manual is quite *‘comprehensive’,* although he hasn’t actually seen it. He presumes that *‘as long as they’ve been taught properly’* and have *‘actually read the instructions’* there should not be a problem as *‘they shouldn’t really need to touch it’.*

People's lives are complicated and the untimely introduction of new practices during the handover period might be ineffective. It seems that the handover material is only consulted when people’s everyday comfort is interrupted, rather than as part of the practice of moving home, perhaps because ventilation and indoor air quality (IAQ) are not as easy to detect as thermal comfort. This leads to a communication gap which may require different types of interventions to address.

Engage residents during and after handover

The RSLs at Case C *'have a very vulnerable client base'* which includes *'a lot of people who haven't got English as a first language'* [Douglas]. To counter this, they have recently '*engaged a graphic designer'* and are trying to introduce *'more pictorial guides'.* It seems that this RSL is aware of their residents' needs, and is gradually its adapting procedures. On another project they produced a DVD for residents:

> *'Our project manager actually walked through the development showing people where everything was and how everything worked. And demonstrating some of the controls' [Douglas].*

Although their efforts were positively received by the residents, Douglas notes that *'it was a lot of work'* and was done in-house by the RSL; when they investigated the potential to commission a DVD like this for all their developments the cost was found to be prohibitively high. However, they hope to move towards this kind of handover in the future. In another example, Richard describes working with a developer who were '*very communicative with their tenants'*:

> *'They produced little labels that would hang round different controls for instance, "this is your boost ventilation", when to press it, and "this is the speed control"'.*

He also recommends *'writing instructions on the product to make it clearer as to what you're supposed to do*'. However, he believes that they provided an *'excessively long user guide'*, which highlights the challenge faced by housing providers in including all the required information, at the same time as creating a concise and useful guide for residents.

Although handover is a crucial period, several of the RSLs continued to interact with tenants for many years after they moved in, which provided ongoing opportunities to engage residents. For example, at Case A, the RSL organised a welcome event for the new residents, to try encourage members of the community to meet and get to know each other. They have continued to organise drop-in surgeries where residents can '*turn up and talk about issues',* as well as running a '*residents panel'* so that *'involvement's encouraged'* and '*they've got access to people should they need it'* (Eddie). However, some of the interventions currently adopted by other RSLs are less inclusive. At Case B, RSL project manager Brian explains how they wrote to all the tenants to remind them to leave the MVHR switched on *'all the time'* and that they should use the boost button when they are cooking heavily or showering. This followed an incident at other parts of this development where damp and mould had formed after residents switched off the AHU to try and save money. Written letters have the potential to exclude people who are not literate or cannot read English well.

At Case B residents who are new tenants of the RSL receive a follow up visit after one month, six months and nine months as part of their *'starter tenancy'* (Brian,). After this period, if there are no problems, residents '*get an assured tenancy confirmed' (Brian)*. The visits are carried out by housing officer Janet and could offer an opportunity for face-to-face engagement with residents on making the most out of their home.

Following the Green Doctor visits Karen (Case A) feels *'very much more conscious'* of her family's energy consumption. Her children are no longer allowed to *'go off to school and leave tellies on and things like that*'. She now fines them if they '*haven't turned them off*' and treats them to a monthly takeaway if they remember to switch everything off. She seems engaged with the RSL's investigations when she adds that *'it might be quite interesting to see what they've found out actually'.* At Case B, Janet explained that they were also in the process of launching their own Green Doctor, and had just started a '*green team'* who were investigating the potential to carry out insulation and retrofit interventions across their stock; this may offer further opportunities for 'disruptions' to occur.

7.4.3. Summary

This chapter discussed how the current handover arrangement could be constraining residents from adapting to their new ventilation systems. This may be because it is too narrowly focused on imparting 'institutionalised knowledge' rather than engaging all four elements of the ventilation practice, namely know-how and embodied habits, institutionalised knowledge, engagements and technologies.

Through presenting a series of disruptions, where residents' awareness of otherwise hidden ventilation components was temporarily raised, this chapter showed how some people's ventilation activities are changing, but also highlighted that the process of change continues long after homes are handed over to occupants. Although these events varied in terms of timing and location and involved varied actors such as RSLs, POE consultants and family members, they shared the fact that they appealed to residents' embodied know-how, past experiences and moral meanings and engagements. As well as focussing on improving the O&M manual and handover procedures, practitioners could also leverage these moments to help residents to develop more sustainable ventilation practices.

Chapter 8: Discussion and conclusion

8.1. Summary of research context and rationale

The aim of this thesis has been to explore how residents of low energy housing (LEH) with whole house ventilation (WHV) technologies are ventilating their homes, and to what extent their ventilation practices have adapted since living with WHV in UK housing. The research also sought to understand the potential role of various stakeholders, including architects, contractors and registered social landlords (RSLs), in enabling residents to adapt their ventilation practices to coincide with those which were imagined by the buildings' designers, and which are required to meet current energy performance targets.

Previously, there was no known empirical study specifically examining ventilation practices in UK homes. The context of this research is the construction industry drive towards WHV as a way of delivering very airtight LEH, in response to zero carbon homes (ZCH) targets and UK government and EU mandates to reduce carbon emissions. However, this thesis challenges the notion that simply installing new technology can instigate social change (Shove et al., 2012).

Chapter 2 argued that the technical and regulatory context has created a situation where occupants may need to adapt to not just one ventilation technology, with its associated practices, but potentially three or more different types. This configuration also anticipates that residents understand systems and processes that even the technical community struggle with. The historical analysis highlighted how the current arrangement of ventilation and housing design has coevolved alongside developments in the way society is organised. Consequently, domestic ventilation was framed as a socio-technical phenomenon from the outset.

The unit of analysis in this thesis is 'social practice' as distinct from 'human behaviour'. The significance of this distinction was elucidated in Chapter 3 which reviewed qualitative and quantitative literature from various disciplinary perspectives in order to situate this research within the existing state of knowledge about how people ventilate their homes. The literature review identified that domestic ventilation research to-date has been carried out predominantly within an individualist paradigm (Dubrul, 1988, Mansson, 1994, Fabi et al., 2013). The individualist approach to studying 'behaviour' was found to be lacking, as it prioritises individual actions over collective experiences. This highlighted a research gap around more holistic studies of ventilation phenomena, which this thesis seeks to fill. Social practice theory (SPT) was identified as an appropriate lens through which to generate insights about domestic ventilation, because it overcomes the polarised concepts of structure and agency and offers a set of concepts with which to unravel the complexity of daily life. The main concepts borrowed from SPT are Schatzki's notion of 'prefiguration', in which arrangements of practices and entities can enable and constrain certain activates, and Gram-Hanssen's framework for empirical research into consumption practices, which conceptualises practices as comprising know-how and embodied habits, institutionalised knowledge, engagements and technologies (Schatzki, 2002, Gram-Hanssen, 2011).

This thesis has addressed an interdisciplinary research problem. Chapter 4 positioned the work between three academic domains which are themselves interdisciplinary: architecture, engineering and science and technology studies (STS). An interpretive research paradigm and qualitative methodology were selected as the most appropriate strategy for answering exploratory research questions in an area which has not been previously studied in detail. The research took the form of a case study investigation of three RSL-developed and managed housing schemes, each with a different WHV technology: mechanical extract ventilation (MEV) at Case A, mechanical ventilation with heat recovery (MVHR) at Case B and passive stack ventilation (PSV) at Case C. Fieldwork was conducted in 2012 and 2013 and comprised 15 resident interviews and walkthroughs alongside 13 in-depth interviews with members of the design team RSLs associated with each case. Design and construction documents completed the dataset.

8.2. Key findings in relation to research questions

The key findings of the thesis are discussed in this section, with reference to the four research questions. Although this research focuses on ventilation practices and technologies, the ideas discussed in this section may also apply to other fixed building services which were previously unfamiliar to the residents.

In Chapter 5, the concept of ‘arrangements’ was borrowed from Schatzki (2002) to investigate, explore and discuss how the physical configuration of homes and their ventilation systems, both ‘as designed’ and when inhabited, can prefigure (constrain and enable) different ventilation practices. The findings of this chapter address research questions 1 and 2, as discussed below.

Q1 How does the design and construction of homes with WHV systems create a physical arrangement which can constrain and enable residents’ ventilation practices?

At Case B, a fragmented design and delivery team meant that ventilation wasn’t considered until after the planning stage; consequently, design decisions made at the earlier stages of the project narrowed the available choice of ventilation strategy. For example, to successfully integrate PSV into a building, this system needs to be considered from the outset, as demonstrated by Case C. This discussion highlighted a potential issue with the contractual process of procuring new homes.

Furthermore, the architect at Case B was not responsible for choosing the ventilation strategy. Instead, the decision was made by the contractor-developer, as a way of meeting a certain sustainability performance target at lowest cost; therefore, neither the layout of the dwellings, nor the needs of residents, were considered as part of the decision. This compromises the system that is installed; for example, ductwork may need to be routed though areas not designed for this purpose. At Cases A and C, the architects selected the ventilation system, specifying the same technology they had in their own homes. Because System 1 (background ventilators and intermittent extract fans) was assumed at the planning stage of Case B, space was not allocated for the MVHR unit; therefore, the already limited storage provision had to be reduced further to accommodate this piece of equipment.

Ventilation systems are just one part of the whole physical fabric which needs to be considered when designing and constructing a dwelling. The above discussion demonstrates how the choice of ventilation strategy is not a 'rational' decision, based on systematically evaluating the requirements of the project brief, but rather is influenced by structure of the design team and the previous experiences of its members, as well as the planning and regulatory system, costs and compliance procedures. For example, the contractor at Case C noted that:

> *'I think we're probably approaching it from an energy point of view and from a Building Control point of view so in meeting building control we're looking to achieve the energy requirements, so therefore we're looking for heat recovery as a way of doing that. So we're doing that whether or not that is the best system to use or not. It basically enables us to meet the regulations; we have a whole range of things to meet.' (Martin)*

This resonates with the work of Lutzenhiser (1993), who argues that industry networks, protocols and bureaucracy can form 'lock-ins' for certain products and impede the way organisations make decisions. Today's LEH are getting more and more complex and people may be struggling to cope with this (Stevenson and Rijal, 2010). For example, the windows in a new home are intended to fulfil multiple functions such as safety, ease of cleaning and maintenance, insulation, visibility, daylight, and sound protection, as well as providing different levels of ventilation at certain times of the year.

At Case A the homes were designed with night ventilation in mind to prevent overheating during summer. However, the combination of lightweight construction methods and rooflights, selected as part of wider sustainability goals relating to reducing embodied carbon throughout the supply chain, may not be ideal for night cooling, which can benefit from the presence of thermally massive materials to operate effectively. Here, contradictions in the design ambition of a project are materialised into a ventilation strategy which does not necessarily align with the building fabric strategy, and into a physical configuration which constrains residents' ability to make use of the intended night ventilation strategy. This demonstrates the dynamic relationship between ventilation and building fabric; it is not possible to discuss one without acknowledging the other (Lowe et al., 2012).

Furthermore, the previous paragraph shows how the socio-technical arrangement which encompasses the production of new homes (including actors such as architects or entities such as the Local Authority planning system) may enable or constrain adaptation, by making it easier or harder for people to use their homes.

Q2: How does the process of inhabiting a home conflict with residents performing ventilation as the designers intended and anticipated?

People live in a home and not in a 'design'. Therefore, design and construction assumptions can only be tested out when a home is occupied and the technologies in it are being used (or not used). The investigations at Case A found that the practice of night ventilation was something which only existed in the imagination of the architect, and was not being performed in the built and inhabited homes. The reason for this misalignment between design intent and inhabited reality includes residents' reluctance to leave windows open for night ventilation because of concerns over security, rain ingress, and fear of insects entering their home. Furthermore, a missing component, the opening pole, prevented residents at two cases from opening their rooflights until they complained to the RSL.

Schatzki (2013) points out that designers and producers have a *'special hand in configuring practices'*, hence they *'enjoy the privilege of initiative – in constructing and laying out settings (….) others must accommodate themselves.*' (p.46) However, although residents of social housing do have to '*accommodate themselves'* within the fabric parameters they are provided with, to a certain extent residents can, and do, reconfigure the spaces to suit their own lifestyles and develop workarounds to certain problems, although this may result in unexpected consequences that they are unaware of. Chapter 5 demonstrated how the process of inhabiting a home involves introducing new entities, such as furniture and other personal possessions, into the designed space. New furniture may hide or obstruct certain components of the ventilation system. For example, at Case A, the wall-mounted trickle vents were found to be obstructed by book shelves, wardrobes and bunk beds; this could reduce the airflow through them. In other instances, residents' occupation and modification of a space compromised ventilation components by squashing MVHR ducts, obstructing extract vents, blocking under-door air gaps and concealing MV units from view. In all cases, some feature of the combined built and inhabited arrangement prevented residents from ventilating their homes as anticipated or intended. Instead, some residents participated in unintended ventilation practices, as discussed below.

Q3: How are people who live with WHV ventilating their homes?

In Chapter 6, Gram-Hanssen's framework for empirical research into practices was used as a lens through which to examine how residents are ventilating their homes. According to Gram-Hanssen (2011), practices comprise four elements, namely know-how and embodied habits, institutionalised knowledge, engagements and technologies. The findings of this chapter address research question 3, and are discussed below.

Much of a ventilation practice takes place through the routinised performance of embodied activities. An important goal of these routines is to freshen air by using windows and other openings. Although windows are opened at various points in the day, there are denser clusters of such activities around certain parts of the daily cycle: getting up, leaving for work or school and returning to the home towards the end of the day, and while preparing for bed.

Furthermore, some routinised practices are particularly prominent around certain seasons; for example, window opening is often, but not exclusively, discussed in relation to summertime and warm weather. Evidence was also found suggesting that practices need to be performed frequently in order to persist.

Past experience plays an important role in developing embodied ‘know how’, as exemplified by one resident’s delight in recreating his parents’ window opening routine for his own children. This demonstrates how, despite no longer being required to provide sufficient fresh air to the dwelling and after supposedly being replaced by a new technological solution, certain existing habits may persist within the new arrangement.

Several residents were found to leave windows open during the day and at night, regardless of external temperatures; this activity has repercussions for heating energy consumption and is not accounted for in steady state housing energy consumption models, such as the Standard Assessment Procedure (SAP) (see 2.1.4). This supports the findings of Brundrett (1977), who reported that people in Britain tend to open windows throughout the year, as well as research by Lindén et al. (2006) and Guerra-Santin and Itard (2010), which found that 40% and 50% of people respectively participate in daily wintertime airing using windows. An unexpected reason for over-use of windows is exemplified by the family of Fara, who accidentally left a window open when they went away on holiday, which then warped in the rain and no longer closes all the way. The physical fabric of the dwelling has now been altered in such a way that airflow is increased and airtightness is compromised. In this particular case, the residents have little means of rectifying the situation.

Conservation of energy was not found to be a strong part of residents’ engagement with WHV and windows. Only one resident expressed concern with the energy implications of opening windows while the heating was on, which contradicts the findings of Price and Sherman (2006) and Park and Kim (2012) though it corresponds with those of Soldaat and Itard (2007). While the later study was based on Dutch housing, the former two studies took place in the US and Korea respectively, where the socio-technical arrangement may differ more than in the Dutch content (e.g. climate, housing construction materials, lifestyles).

Ventilation through windows is used as a way of negotiating individual thermal comfort preferences. Windows enable members of the household to adjust the temperature in their immediate environment without having to interact with the heating technology, to which they may not have access. Here, the socio-technical arrangement of the home prefigures the frequent use of windows by inhibiting access to the heating and making window opening a more convenient solution to meeting residents’ needs.

While residents sought to make sense of the WHV as best they could, many were confused about what the technologies were supposed to do, how they worked and what, if anything, they, as occupants, should do to prevent problems. Because residents did not fully understand the systems, or know if they were working to provide appropriate ventilation, they default to using the systems that they do understand, namely ventilating through windows. This action could, potentially, offset the very reason for installing this new technology in the first place – to save energy. Lack of institutional guidance was also found to hinder resident's understanding of, and engagement with, mechanical ventilation systems, in a study of the 'usability' of domestic control interfaces conducted by Stevenson et al. (2013). As well as lacking technical, or 'institutionalised', knowledge, there was also little embodied know-how around the new WHV technologies. Instead, rules were more prominent in the way residents engaged with components of these systems. Some of the rules which residents recalled include being advised not to switch the MVHR off, not to try to change filters themselves, not to close trickle vents and not to install cooker hoods. Notably, these rules relate to 'not doing' certain things, and exclude the residents from interacting with parts of their ventilation system. For this reason, some residents are not the sole practitioners of ventilation 'practice' but share this role with their landlords and subcontractors, who are responsible for the systems' maintenance.

Where present, kitchen booster switches are used by many, but not all, residents to remove steam, smells and smoke whilst cooking. However, the booster was often supplemented by windows as it was felt to be insufficient to deal with heavy smoke or strong smells. Furthermore, while boosters were found to occasionally break or block up, windows do not suffer the same issue and therefore could be considered more reliable as well as being intuitive and familiar to use.

Summertime overheating was found to be a concern at all three cases. There is growing evidence of overheating in new housing and this is expected to continue as summertime temperatures increase in the future (Beizaee et al., 2013, ZCH, 2015b). Residents initially attempt to mitigate against uncomfortably hot temperatures by using windows, doors and, where possible, rooflights. However, many residents struggled to achieve satisfactory conditions using solely passive strategies. Furthermore, in certain situations, residents did not feel it was safe to leave windows open at night or when leaving the house, for fear of burglary or rainwater ingress. Overall, over half of residents were using electric fans to supplement air movement, with a minority also resorting to purchasing active cooling systems. These additional components are not part of any of the designed or intended ventilation strategies but appear to form part of the wider practice of ventilating low energy homes. This may indicate how practices could change in a direction that is unforeseen and unintended.

The exploration of ventilation routines indicates that individuals do not always use technologies according to the design intent. This finding supports previous studies by various authors (Macintosh and Steemers, 2005, Stevenson and Rijal, 2008, Bell et al., 2010, Banfill et al., 2012, Stevenson et al., 2013).

Instead, residents find their own ways to cope with their ventilation systems, despite certain struggles, by using alternative or additional technological devices such as windows and fans as workarounds. Ventilation takes place as part of a host of interconnected lifestyle activities, which relate to providing and maintaining a comfortable, safe and healthy home environment. In this sense, it could be said that people expect more from their ventilation system than the IAQ that the current building regulations seek to provide (e.g. relief from health conditions). Foulds et al. (2013) similarly treat ventilation as part of several other domestic practices. Although analysing the data with reference to the four elements allowed practices to be examined in some detail, the practices themselves do not fit neatly into compartments. Instead, they are dynamically connected clusters of embodied routines, conventions, meanings and objects. It is these complex bundles of temporal rhythms, lifestyles, and past experiences which constitute a ventilation ‘practice’.

Q4: How might interventions be constructed by different actors to help residents use ventilation as intended?

ADL1 (Part L of the Building Regulations) recommends that residents are provided with operating and maintenance instructions to help them use the systems in the most efficient way (2.1.2) (HM Government, 2010c). However, the analysis presented in Chapter 7 indicates that the O&M manual is not the only tool available to these groups of residents to learn about the ventilation and other systems in their house; rather, it is just one of a number of resources mobilised by tenants to ‘make sense’ of a particular technology, when they encounter it for the first time, and as they attempt to control it and adapt to it. There may be an over-reliance within the construction industry on the O&M manual to provide training to new residents; instead, perhaps designers and housebuilders could benefit from understanding that domestic practices are too complex and interconnected to be *‘taught’* using a manual.

Although instruction manuals can provide technical knowledge, they do not seem to be effective in engaging with embodied know-how, an important element in the actual performance of a practice. The discussion of night purge ventilation at Case A is an interesting example of how the O&M manuals fail to address the complexity of living in a LEH with WHV. In anything larger than a studio flat, night purge ventilation relies on a complex interaction and coordination between household members and the physical arrangement of the home, alongside an understanding of external weather conditions, to ensure that windows are closed, shaded and opened at suitable times, so that comfort is maintained. However, the manual provided at this case doesn’t refer to night cooling, rooflights or windows and therefore constrains residents’ ability to take part in the practice unless they find another means of accessing this esoteric knowledge.

Furthermore, the timing of the delivery of the O&M is not ideal, as it coincides with an intensely busy period for residents, contractors and RSLs, all of whom struggle to focus on its content when they are preoccupied with other matters such as commissioning a completed project or moving home. Therefore, the current social configuration of the handover, as well as its format, content and timing, is not effective at recruiting practitioners to new ventilation practices which might enable them to live in a more efficient way. Issues with the timing and format of handover procedures were also raised by Stevenson et al. (2013) and Carmona-Andreu et al. (2013), who calls for a more ‘*user centred handover’* (p.9).

The struggle of some residents to make sense of their ventilation system demonstrates how simply inserting a new technology (WHV) into an existing arrangement (UK housing industry) is not delivering the changes in energy efficiency and ventilation practices that the industry and government expects or hopes for. This challenges the suggestion by Gram-Hanssen (2008a) that domestic routines change immediately following the introduction of a new technology; instead, practices appear slow to change and many residents were found to continue with old routines long after WHV was introduced. This may be because the structure is changing faster than practices and people cannot keep up. That is not to say that people should be blamed for 'bad behaviour'; instead, practitioners and researchers are urged to look more carefully at the context which surrounds the housebuilding industry, and try to engage with them and their practices (e.g. designing and constructing), rather than concentrating their efforts on changing residents 'behaviour', as is often the case now. A similar argument is leveraged by Heaslip (2013), who argues that responsibility for the *'usability'* of technologies lies with designers (p.201).

However, there is some evidence that practices may be changing. The residents who successfully adapted their lifestyles to the new ventilation experienced events which not only enhanced their institutionalised knowledge, but also encompassed the other elements of a practice (technologies, know-how and engagements). The 'disruptions' introduced in Chapter 7 show how interactions between residents and the professionals involved in designing, constructing and managing their homes can temporarily reveal otherwise hidden components to residents, or introduce them to different sets of actions, thus enabling people to participate in new elements of ventilation practice. These events took place not only during handover, a period typically associated with learning about new systems, but also later, during post occupancy evaluation (POE) research, routine maintenance and ongoing aftercare. This indicates how the timing of delivering new knowledge should not be limited to the period immediately following occupation but that opportunities to facilitate adaptability can continue throughout a building's lifetime.

Section 7.4 discussed the role of RSLs in helping residents adapt to new ventilation technologies. RSL are uniquely positioned as intermediaries between designers, and end users of ventilation systems. Rather than focusing on individual residents, interventions to encourage lifestyle changes from residents (e.g. to encourage residents to incorporate filter changing into household maintenance routines) could make use of existing relationships between tenants and housing officers. However, the strength of communication between tenants and housing management varied between cases and the success of such interventions may depend on the extent to which RSLs see themselves as having a role to play in changing ventilation practices.

Architects and designers may have the necessary skills to prepare handover and induction material which addresses the different elements of practice, as they are experienced in communicating visually, and, at the cases studied here, were more likely than contractors to visit the schemes post-completion. However, presently Stage 7[178] activities are not typically part of an architect's appointment and therefore their opportunity to engage with occupied projects takes on a voluntary, and therefore limited, role. Programmes such as Soft Landings[179] attempt to overcome this problem (e.g. Way and Bordass, 2005), but are currently not widely employed in practice, especially in the domestic sector (Gul and Menzies, 2012).

The case for '*making feedback and post-occupancy evaluation routine'* is not new (Bordass and Leaman, 2005). However, the arguments in favour of this process tend to focus on influencing *'those who commissioned and undertook the design and building work'* (e.g. Bordass and Leaman, 2014, p.161), whereas this thesis argues that these activities can also benefit residents and help them adapt their lifestyles to accommodate new technologies.

8.3. Implications of this thesis for practitioners

This section considers the implications of this work for stakeholders involved in the design, construction and management of new homes.

8.3.1. Architects and Contractors

Design challenges

The new homes with WHV were found to be prone to overheating during summer. A number of design issues were identified which constrain the residents' use of natural ventilation and in particular night ventilation to mitigate excessively high temperatures. Consequently, many residents had introduced additional ventilation and cooling technologies into their homes and routines, which has implications for energy consumption. Security concerns prevented some residents from leaving windows open while they were out or at night, despite the presence of safety latches which limit the extent of window opening. Designers could acknowledge this culture of fear in relation to comfort among certain vulnerable groups and consider alternative arrangements such as those including larger secure ventilation openings (e.g. secondary window openings protected by grilles and louvres) to enable residents to make greater use of natural ventilation.[180] Although rooflights offer benefits in terms of natural light and (potentially) ventilation, they also compromise the protection offered by a conventional roof. Furthermore, rooflights contribute directly to summer overheating as their geometry considerably adds to the solar gains during summer, compared to vertical windows which let in solar gain during winter,

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[178] This refers to the RIBA Plan of Work Stage 7 'In Use' (RIBA, 2013b).
[179] A useful summary of the Soft Landings process is available at https://www.bsria.co.uk/services/design/soft-landings/ (accessed 08/07/15).

[180] See Chiu et al. (2014) for an example of '*custom-made high-performance windows with side vents to allow good ventilation (….) occupants could feel entirely secure even with vents open'* (figure 1).

which is when it is needed most. Consideration could be given to whether they are really necessary and improved configurations should be tested to minimise rainwater ingress. Alternatively, rooflights with automatic control by rainwater sensor are available, although the cost may be prohibitive in the case of social housing contracts. A more usable window design could also incorporate insect screens, especially for homes located close to bodies of water.

Designers face a challenge regarding the most appropriate choice of building materials, and lock-in arrangements or '*linkages'* between '*infrastructional players'* can stifle innovation (Lutzenhiser, 1993 p.276). However, it is important to weigh up the relative merits of thermally massive or lightweight construction, rather than simply follow the status quo, as this will affect the internal conditions and can constrain residents' ability to maintain comfort with minimum energy use. The orientation of buildings and their windows is also important as excessive solar gain can cause overheating, and unfavourably positioned glazing (e.g. rooflights) can render a home particularly susceptible to this problem. This study found that the single aspect, west facing apartments at Case B were especially prone to overheating as were the timber framed houses at Case A (Figure 34, p.120, Figure 44, p.137). South and west facing openings benefit from horizontal shading to limit solar penetration during summertime. None of the schemes visited included external shading of any kind, something which is recommended to reduce overheating and help produce homes which are resilient to climate change (Pelsmakers, 2012).

Overall, there only seems to be a partial understanding by designers of the role of passive solar, thermal mass and ventilation in well insulated buildings and it does not appear that design communities are at present equipped to make appropriate judgements that balance the complex requirements of a low energy home. Until there is some kind of common correct understanding of what the system is supposed to do, design teams are limited to picking up on specific elements of the problem, without the ability to focus on the whole.

An integrated design team

It is important that designers consider the ventilation strategy from the conception of a project rather than post-planning. This is because some strategies (e.g. PSV) require certain geometries in order to function correctly and leaving such decisions until later on can constrain the range of possible options and result in inappropriate specification. Therefore, certain consultants may need to be brought on board earlier on in the design process so that they can advise on appropriate configurations before critical design decisions are made. In particular, the separation of planning and construction packages between two different architectural practices was found to cause a break in communication, which had detrimental consequences. For example, the planning stage architect had never visited the project, either during construction or after completion, and therefore cannot be expected to incorporate lessons learnt from the occupants' experience into his future work. This is an example of how, when individual organisations work in 'silos', innovation may be constrained. Furthermore, when decisions are made early on in the design process, before the contractor is appointed, contractors are excluded from contributing their own expertise to the choice of ventilation system, despite having valuable experience of installing different types of ventilation technologies:

> *'We don't have the luxury of thinking "actually these people would be better off with trickle vents and extract fans than would be with heat recovery"' (Martin)*

On the other hand, at the cases where design teams were engaged across all the work stages and beyond completion, the projects benefited from improved dialogue and cross-learning between the actors, who therefore may have been in a better position to deliver successful homes to their client.

Communicating design intent

Design intent was not communicated successfully to the residents of the new homes. This meant that they were often unaware of how systems were expected to work, or of how they could moderate their environment to achieve comfort and save energy. For example, information such as the potential for rooflights to contribute to night ventilative cooling was articulated by the architect but was omitted from the O&M manual. Furthermore, the use of windows for ventilation was not mentioned in any of the user manuals, despite forming a vital activity in the practice of ventilation.

Across the cases, architects, contractors and RSLs were involved in the production of O&M manuals. However, the manuals were not particularly effective in helping residents adapt to their new ventilation. As discussed in section 8.2, designers may be well positioned to take a more active role in the design of handover information. This highlights the importance of remaining involved in projects beyond practical completion and through Stage 7, both in terms of informing future projects and improving the resident's experience. This latter point is extremely important, as residents were found to continue learning and adapting to the new ventilation technologies through interactions with expert stakeholders long after handover. A similar point is raised by Heaslip (2013), who suggests that '*the role of the designer is to create the context for successful interactions'* (p.220). This could be achieved by facilitating a more comfortable alignment between people, technology and building fabric.

Even when architects are not able to prepare the O&M manual themselves, it is important that they communicate the design intent around the physical fabric that they have designed to whoever is responsible for the handover, such as the RSL, so that housing officers do not have to second guess what the architect had in mind. This discussion resonates with Janda's argument that architects and design professionals need to take a more *'interactive role'* and '*seek ways of integrating user involvement in building performance'* (Janda, 2011, p.16).

8.3.2. RSLs and Housebuilders

Design stage

RSLs and housebuilders are often responsible for choosing and appointing the design team. In this study, the most effective teams were the ones who had worked together in the past and shared certain common values and vision; furthermore, their members maintained contact throughout the design and construction process. By being informed about the challenges facing residents as they adapt to new technologies, RSLs or developers can be better clients and manage their teams to deliver the best possible outcome. For example, it is important to consider ventilation strategies early on in the design process rather than after key architectural gestures have been made, by which point certain strategies are no longer practical. Furthermore, bringing contractors on board earlier on in the process can enable them to work more closely with architects to develop effective solutions. For example, at Case C, the RSL appointed the whole design and construction team from a project they admired, which created a much more cohesive design process with strong communication between different actors.

This research suggests that handover is a critical part of the learning process, and it is recommended that housing providers allow for the cost of a more integrated handover at the project outset. This resonates with the work of Loosemore and Richard (2015), who suggest that one way of being a better client is by not automatically equating lowest cost tenders with best value for money.

Participants reported several instances which suggest that decisions were made based on the requirements of the CSH, and that design teams were defaulting to various systems to achieve a certain SAP rating without a clear design understanding of the implications. Schweber (2013) warns of the constraining impact of building standards on sustainability in practice. For example, although CSH points are awarded for the inclusion of O&M manual this does not appear to have manifested in actual improved sustainability at any of the cases. The requirement for CSH as a planning requirement was withdrawn in May 2015 (DCLG, 2015b). This provides both an opportunity and a risk for housebuilders to formulate their own definitions of sustainability, which might encourage innovation.

Handover

RSLs play an important role in the arrangement of the handover of the completed building to its users. Therefore, as discussed in section 7.4, they may be in a position to create a process which helps their tenants to live more sustainably and comfortably. There is certainly scope for RSLs to take a more active role in preparing the O&M manuals. A suggestion for improving the presentation of the content in the O&M manual is to attend the use of language to match the needs of the expected reader. This communication issue is important for RSLs, particularly those who are managing housing in an ethnically diverse Britain. For example, landlords could consider translating documents into relevant minority ethnic languages, or try to write in simpler language that children and young adults (who may be translating for their parents) can relate to.

They should also respect physical and cognitive disabilities when communicating with tenants. In many cases, the format and layout of the O&M manual could be improved. Notably, the RSL at Case C had engaged a graphic designer to make the manual stand out and be more visually appealing and had also trialled a DVD manual; these are interesting ideas which could be developed further.

An important shortcoming in the O&M manual at Case B was that only a generic manufacturers' product manual was provided to describe the MVHR system, which caused confusion for the residents. A more bespoke approach, though time and resource consuming, may be more effective. Finally, the delivery of the document is worth considering further. In each project, the housing officer is positioned as the point of contact between the residents and the designers and management at the time of the handover. This highlights how important it is to engage the housing officers at each project and not just focus on upskilling technical or management staff.

The "Domestic Ventilation Compliance Guide" (HM Government, 2010d) provides a useful resource which outlines installation, inspection, testing and commissioning requirements for the different systems. The document stresses the importance of commissioning technologies properly to make sure that they are working correctly at handover, so that residents have the best possible chance of successfully incorporating them into their lifestyles. Furthermore, as suggested by POE consultant Michael, there should be a final commissioning of MV services *'towards the end of the defects period'* as filters in new homes, which tend to have more moisture and dust in them, get *'clogged up quite quickly'*.

A limitation of the building regulation requirement to provide an O&M manual is that they only refer to the building owner, who is not always the same entity as the resident. This raises two issues. Firstly, what initiatives are there to encourage social or private landlords to engage with residents to help them adapt to new technologies? Secondly, what can be done to help residents in privately-owned housing, where there are no landlords to act as intermediaries? A final point to consider is that subsequent tenants will not have such ready access to members of the design team as the participants of this study did, and how best to pass on the insights from the interactions between the first generation of occupants and the design team to subsequent tenants is an interesting challenge to consider.

Aftercare

The residents' learning process does not end immediately after handover; numerous opportunities exist for RSLs to engage with their tenants. By staying in touch with residents, either by carrying out POEs or through initiatives such as Green Doctor, RSLs can play a more active role in shaping activities, and may be able to influence the trajectory of practices. Certain pieces of information could be provided at a later date rather than during the intense period of handover. For example, sessions on maintenance requirements of any fixed building services, such as MV filter changing and purchase of replacement filters could be run separately. Here, procedures could be demonstrated by the facilitator and practiced by residents so that they learn through experience rather than by reading or listening (Kolb, 1984, Morss and Murray, 2005). Initially, residents may need to be reminded when it is time to change filters. Some models of fan unit include a light that changes colour when the filter needs to be changed, but this was not a feature at any of the cases studied herein.

Presently, it appears that residents are unable to tell whether a system is faulty (i.e. poorly installed or commissioned), and, rather than seeking help to fix the problem, they may resort to developing alternative workarounds to problems, such as purchasing a laptop to work in an alternative room which is less hot, or opening the kitchen windows instead of cleaning out an extract vent. However, just because a system is complex, doesn't mean people cannot get used to it (Heaslip, 2013). Instead, care should be taken to provide opportunities for residents to learn and engage various elements of an anticipated practice, rather than just fed technical knowledge, somewhat ineffectively.

8.3.3. Recommendations for practitioners

This section draws out practical recommendations for design teams and housing providers, based on the above discussion.

Recommendations for Architects and Design Teams

- Include larger secure ventilation openings for safe night ventilation.
- Avoid use of rooflights and, where felt to be necessary, use configurations that minimise risk of rain ingress or specify self-closing systems with rain sensors.
- Include insect screens on openings intended for ventilation.
- Avoid single aspect west facing apartments.
- Provide external horizontal sharing on south and west facing glazing.
- Train design team to understand the roles of passive solar design, thermal mass and ventilation in providing thermally comfortable environments and avoiding overheating.
- Consider the most appropriate ventilation strategy and system from the project briefing stage rather than post-planning.
- Bring environmental and energy consultants on board as early as possible in design process to avoid lock-ins to inappropriate technologies.
- Visit projects post-completion and commit to carrying out post occupancy evaluation, ideally over a period of several years, to collect feedback from building users and managers and incorporate lessons learned into future projects.
- Engage with contractors as early as possible in design process to benefit from their practical experience of installing different types of ventilation technologies.
- Put in place processes to communicate design intent to the building users and management during and following the handover, e.g. if rooflights are part of the night ventilation strategy ensure residents and housing officers are made aware of this, either through building user guides, inductions or other forms of communication.

Recommendations for housebuilders and RSLs

- Consider the impact of using separate design and delivery architects on project outcomes. If this procurement route is necessary ensure protocols are put in place to allow for sufficient briefing and communication between design team and to avoid decisions being made at planning stage which later constrain the delivery team.
- Provide a clear brief to design teams which covers aspirations for project and requirements of building management and residents.
- Include information about operation of windows in building users guides in addition to instruction manuals for mechanical systems.
- Include design teams and contractors in production of building user guides rather than outsourcing to sub consultants.
- Consider ventilation strategies early on in the project process and include requirements for a more user-centred approach to design at the briefing stage.
- Bring contractors on board from the outset so they can work together with architects to develop effective solutions.
- Appoint design and construction teams who can demonstrate their commitment to a collaborative process rather than working in isolated ‘silos’.
- Set aside part of the project budget for a more integrated and involved handover to client and residents and do not conflate lowest cost tenders with best value for money.
- Consider how and when the building user guides are delivered to residents and engage housing officers more fully in the handover process.
- Provide training for housing officers to understand intended operation of ventilation systems.
- Carry out a second commissioning of ventilation systems toward the end of the defects period.
- Develop processes to ensure building user guides are kept up to date and made available to subsequent tenants and not just the first occupants.
- Follow up initial handover with check-ups and consider participating in schemes such as Green Doctor to continue to help residents to use their homes more efficiently and effectively.
- Identify maintenance requirements of ventilation systems before residents move in and make sure those who will be responsible for their uptake are fully briefed from the outset.
- If residents are intended to carry out their own maintenance consider sending regular reminders to change filters or specifying systems which include a colour changing pilot light when cleaning is required.

Recommendations for compilers of building user guides and O&M manuals

- Invest in more usable building user guides for residents.
- Ensure all text is written in in plain English.

- Translate documents into relevant minority ethnic languages.
- Engage graphic designers to communicate information more visually,
- Respect diverse needs and disabilities by providing alternative guides, e.g. in braille and audio formats.
- Avoid simple reproductions of technical product manuals and do not confuse residents by providing generic product information which is not relevant to the particular installation.

8.4. Implications of this thesis for research communities

8.4.1. Contribution to social practice theory

This thesis presents the first piece of empirical research to apply SPT specifically to domestic ventilation. Unlike other studies of practice, this research drew on the work of Schatzki (2002) in its focus on incorporating the physical arrangement of building fabric into the analysis. In order to do this, non-resident actors involved in the design and construction of LEH were included in the study to explore how the physical arrangement came to be the way it is. Considering non-residents in relation to domestic practices provided a novel perspective on how practices are prefigured before the occupants enter the dwelling and encounter the ventilation components for the first time.

However, the thesis also revealed one of the main limitations of SPT, which is that not a theory that can be proven or tested in the conventional sense, but is rather a set of concepts and ideas which provide a lens through which the social world can be investigated in a novel way. This quality makes SPT challenging to operationalise and may explain why its impact on policy and practice have, to date, been limited. It also reveals a research gap for future work in this area to explore.

Key findings of this thesis, in relation to SPT, include the construction of ventilation practice as a routinised activity which overlaps with other domestic practices, and the finding that the different elements of practice (as defined by Gram-Hanssen (2010)) are more prominent around different ventilation components and activities. For example, while window interactions are largely based on past experience and embodied know-how, rather than institutionalised knowledge, ‘rules’ feature heavily around new technologies. By following rules, residents are excluded from parts of the ventilation practice (e.g. maintenance), particularly those relating to unfamiliar equipment. Furthermore, parts of a ventilation practice are performed by different bodies, whilst still relating to the same physical arrangement, for example, a particular home. This challenges the notion that individual humans are carriers of a particular practice; instead, a network of actors appears to have contributed to different elements of observed ‘ventilation practices’.

Ventilation practices are persistent and slow to change, but change does happen. Moreover, it appears that there are ways in which housing designers, builders and managers could influence this change by regularly interacting with residents of new homes with WHV. This opens up a whole new area of research around SPT and the built environment.

8.4.2. Contribution to socio-technical methodologies

This thesis has sought to contribute a genuinely interdisciplinary piece of work to the area of energy demand research. The use of Schatzki's theory to analyse the socio-technical arrangement of a home and its ventilation system, both as a 'design', and as an inhabited reality, is a novel approach which has proved fruitful for this area of research. Gram-Hanssen's four elements of practice framework was also found to be effective at operationalising the theory to provide a secondary conceptual framework for empirical investigation, and also an analytical framework for data analysis and interpretation. This helped generate insights which are relevant to researchers and professionals from a range of built environment backgrounds, rather than only social scientists.

It is important to locate this work in the field of POE. Rigorous socio-technical research is time consuming, and the methodology deployed herein differs from commercial POE projects in that it is qualitative and in-depth, while POEs often deploy quantitative methods, such as questionnaires and energy consumption monitoring, and are conducted rapidly, to tight budgets. However, the kind of detailed, qualitative investigation of a complex phenomenon carried out herein would benefit many researchers, as well as the construction industry, and, resource permitting, could be effectively combined with quantitative methods to provide a more complete evaluation of building performance.

Some of the challenges of true interdisciplinarity became apparent while doing research at an institution where this kind of approach is not yet mainstream.[181] For example, there were notable differences between colleagues' understanding of certain terminology, and it was not always straightforward to persuade others of the value of a qualitative, socio-technical approach. This highlights the rhetorical nature of current interdisciplinary research; in reality genuinely integrated work is rarely undertaken and more needs to be done to encourage research which sits, sometimes uncomfortably, between academic disciplines.

8.4.3. Contribution to built environment research

This thesis has presented an in-depth study of domestic ventilation practices. Domestic ventilation is an extensive research area, but much of the work to-date has been carried out from a techno-economic perspective: this research presents an alternative, socio-technical, approach which complements existing studies. It also confirms the findings of earlier, quantitative, studies, about the tendency of people in Britain to open windows year-round.

Within the UK housing industry there are already several technological ventilation solutions to choose from. Based on the findings of this thesis, the emphasis should now be on making these

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[181] This research is funded by EPSRC and is part of the Centre for Doctoral Training in Energy Demand Reduction and the Built Environment, a programme which is more closely aligned with the natural sciences and engineering disciplines.

systems work in practice, rather than dedicating time to developing new solutions. Heiskanen and Lovio (2010) made a similar point regarding the uptake of energy efficiency innovations in new Finnish housing, where gaps between experts and laypeople were found to be the main concern, rather than technical shortcomings. When designing and constructing housing in the UK, the end user is rarely known, let alone consulted (less than 10% of homes are self-build (OFT, 2008)). Therefore, any ventilation strategy being proposed or tested needs to be robust to different practices and must not rely on rigid assumptions about people's lifestyles.

The introduction of WHV means that homes are becoming increasingly complex. As Stevenson and Rijal (2010) put it '*housing occupants are effectively the 'building managers''*, yet they are not trained facilities managers and cannot be expected to immediately understand a new system without any guidance. This is evident from the residents' experiences which were recounted in this thesis; many people were found to be struggling to make sense of the ventilation systems in their homes. It was also unclear whether the design team and building managers understood exactly what the system was supposed to do. The interconnectedness of heating, ventilation and thermal comfort needs to be considered: ventilation is hard to isolate from other concepts. In particular the issue of overheating was raised throughout the thesis, and the seemingly widespread use of electric fans in this sample should be of interest to building researchers.

The findings of this work also relate to the notion of *'interactive adaptability'* (Cole et al., 2008); it was found that people have the ability to influence and shape their environment rather than just being passive recipients of a new technology. The concept is summarised below:

> *'Inhabitant experience of comfort and the building systems' performance depend on a form of ongoing dialogue in which the outcome is not predetermined by building design parameters or performance metrics, Instead, there exists a kind of adaptive dance in which both the inhabitants and the building they occupy gradually approach mutually satisfactory outcomes' (Cole et al., 2008, p.335).*

Another issue raised by this thesis is the ethical implication of using human participants, in this case RSL residents (some of whom may be considered a vulnerable group), to test out an innovative housing prototype. Although residents in all three cases seem to be generally satisfied with their homes and there was little evidence of poor ventilation performance (e.g. mould), this may, nonetheless, be a concern for some built environment researchers.

8.4.4. Contribution to policy, building standards and regulation

Chiu et al. (2014) argue that '*end use energy demand policy needs to be informed by a socio-technical approach'* (p.574). There are several recommendations to policymakers that are informed by this piece of socio-technical research, as discussed below.

Although the UK construction industry seems to have accepted MVHR as the new norm (e.g. NHBC and ZCH, 2012), there is still a legitimate debate about whether this is the most carbon saving strategy, especially given the findings presented here relating to the frequent use of windows and the risk of overheating. There may be limited benefit in installing MVHR and specifying a very airtight building fabric, if occupants rely on windows instead of the mechanical system. Frequent use of windows may explain the findings of Laverge and Janssens (2012), who argue that in a European climate '*natural ventilation, simple exhaust mechanical ventilation and heat recovery ventilation have no clear advantage over each other as far as operating energy is concerned'* (p.315). This challenges the calculated theoretical performance of such systems (e.g. Lowe, 2000) and reiterates the importance of testing ideas in occupied buildings.

If MVHR is to be successfully integrated into housing it is important that it is correctly installed as well as being operated effectively. It is surprising that summer bypass mode is neither currently required by the regulations, nor mentioned in the Domestic Ventilation Compliance Guide (HM Government, 2010d). This document may be a useful place to start raising awareness about the increased risk of overheating in LEH. If designers and constructors are not aware that a summer bypass is required in MVHR installations then it may be unrealistic to expect RSLs and residents to understand its importance.

This thesis demonstrates the importance of POE, not only as a method for professionals to learn about their completed buildings and to inform future design decisions, but also as a critical moment in a resident's learning experience of their new home. Currently, POE is a voluntary and infrequent endeavour, but, if RIBA Stage 7 activities were to become mandatory, its use within industry would grow. Additional regulation and guidance may be required around handover procedures and O&M manuals, as these do not to seem to be fulfilling the requirements of ADL1 to conserve fuel and power, yet are currently advised by that document (HM Government, 2010c). Finally, rather than rely solely on the power of technology to stimulate change, demand policy should be informed by evaluations of the '*social transferability of building technology',* so that a new bundle of arrangements and practices could be facilitated which encourage energy efficiency (Shove, 1998 p.1111).

8.5. Reflections on theory and methods

This section reflects on the theory and methods used throughout this research and discusses some of the challenges and limitations of the work.

8.5.1. Social practice theory and multi-disciplinary research

To date, much research based on socio-technical approaches examines large scale phenomena using historical data (Guy and Shove, 2000, Wilhite, 2009, Shove et al., 2012, Sahakian and Wilhite, 2013). In contrast, this study comprises a detailed study of a micro-phenomenon on a small sample of participants, at three case studies. To address this difference in focus, a new analytical framework was developed as part of this thesis, based on the work of Schatzki and Gram-Hanssen.

As discussed in section 3.3.3, the adoption of Schatzki's flat ontology concept helped overcome the challenge of differences in scale (Figure 28, p.89). According to a flat ontology, all social phenomenon are part of the same landscape of interconnected practices and arrangements, and can therefore be analysed according to the same concepts, regardless of scale (Schatzki, 2011). The theoretical analysis framework adopted in this thesis also drew on the work of Gram-Hanssen, whose own empirical work is also based on localised and situated data (heat comfort practices in privately-owned Danish housing). Gram-Hanssen's analytical framework was used to complement Schatzki's concepts of prefiguration and the flat ontology because it provides a concrete and useable set of categories through which to collect, explore and analyse empirical data, obtained through in-depth interviews.

A challenge faced by an individual researcher carrying out an investigation which draws on multiple disciplinary backgrounds is preventing the work from becoming spread too thinly across the broad subject matter. By adopting an interdisciplinary perspective for this thesis it was not always possible to explore all the available data in as much detail as they may have deserved, particularly as using qualitative methods with rigour and integrity is so time-consuming. However, overall, the version of SPT adopted in this thesis provided a useful set of lenses through which to look at the phenomena of domestic ventilation in depth, and enabled comparisons within and across the localised and situated micro-cases. In this sense, it was effective in addressing the complexities involved in understanding what people do, and hopefully presenting them in a way that is accessible to readers from multiple disciplines who are researching and influencing the built environment.

8.5.2. Limitations of method

A limitation of the interview method used in this study is that interview data were collected from residents at a single point in time, while the research topic is concerned with change. A longitudinal approach, comprising multiple interviews with each resident may have helped explore whether changes prompted by 'disruptions' actually developed into new practices. However, this kind of approach would be very time and resource intensive. Most interviews were conducted with just one person, yet many of the households had several residents; consequently, analysis is based on an individual's recollection of their own experience rather than that of the whole household. Future fieldwork could make use of serial interviews to encourage participants to reflect on their routines and ask them to consider alternatives (Hitchings, 2012), or conduct group interviews with multiple household members (Gram-Hanssen, 2010). However, the participants who contributed to this study had already been involved in other research projects and could be said to be suffering from research 'fatigue'; consequently, recruitment for even one, single-person interview proved challenging for each of cases.

The interview as a method relies on participants' memory; therefore their accounts may omit subtleties of which they are themselves unaware. A more comprehensive study could have made use of technical monitoring (e.g. internal temperatures, window opening) to provide wider insights. Detailed measurement of the ventilation units (e.g. flow rates, electricity consumption) were not taken as part of this study, which meant it was hard to establish whether a system was working as designed or not. This information would have helped evaluate whether a resident's struggles or adaptation were in response to functioning or faulty installations. However, this was beyond the scope of this work which was conducted as an individual PhD project and was not linked to a fully resourced research team. This limited the amount of data that could be collected by a single person. Instead, secondary data about building performance were obtained based on previous POE studies; (e.g. temperature, energy consumption and airtightness). However, as a different approach was taken at each case study and the figures were based on reports rather than original data, this information did not prove very insightful and was not included in the final thesis.[182]

If resources allowed, the limited observation of occupants at home could have been enriched though ethnography (Wilk and Wilhite, 1985, Wilhite et al., 1996, Graves, 2010), a method which can provide deep understanding of '*realities and lived experiences'* (Pink et al., 2012, p.2) and which may have been useful for understanding the varying points of view of participants in the different cases (Ragin and Becker, 1992). For example, Bailey et al. (2013) gained insight into '*the process of delivery'* by recording and analysing the handover procedures of a major housebuilder. However, an ethnographic approach may also be restricted to studying particular times and locations and may therefore not contribute much more to capturing the temporality and spatiality of practices.

Opportunistic and convenience sampling was used to recruit participants. At Case B, the researcher was also involved with the POE study which was taking place simultaneously, and was already acquainted with the housing officer, who agreed to be interviewed and suggested another colleague who was also subsequently interviewed. It was important to consider the individual aims and methods of the two studies (i.e. the POE and the PhD) when interpreting the results, and to inform participants exactly what data were to be used for. It was also important to acknowledge the reason why participants agreed to take part in the study. For example, one resident at Case C was specifically introduced to the researcher as the RSL knew she was experiencing problems with the house and suspected that she would be willing to take part. This was confirmed during the interview with Carla, who said '*because I just want things to improve anyway so-- and that's why I agreed to do this*'. This information provides insight into the expectations of certain participants, which need to be managed by the researcher, so as to avoid confusion and disappointment amongst participants.

Another challenge which was encountered was some residents' attempts to please the interviewer. For example, during an interesting digression, Ali said '*I'm trying to focus back on ventilation'.* During transcription, it was noted that participants were quite prone to repeating back what had just been said by the interviewer, so that caution had to be taken when using quotes, not to attribute the researcher's ideas to participants. As discussed in section 6.1.2, the

[182] Some of this data are presented in the detailed case study descriptions in the Appendix.

terms ‘ventilation’ and ‘ventilate’ are not frequently used by laypeople, who were found to refer to ‘airing’ and ‘fresh air’ instead. The different meaning of certain technical terms was also apparent when working with an interdisciplinary supervisory team. However this encouraged clarity of communication in the writing process, which is hopefully manifested in a more readable thesis that can embrace disciplinary differences.

The residents at Case B had only lived in their properties for a short time before the interviews took place (<2 years) so had less experience to recount. However, these residents found it easier to recall the more recent handover procedures, while those who had lived in their homes for many years (Cases A and C) were more able to offer insights about maintenance procedures and their ongoing relationship with the RSL.

The three cases studies comprised RSL-managed housing schemes. The research could have been enriched by considering additional cases based on different housing tenures such as privately owned and privately rented accommodation. The use of a small sample and a case study approach means it is not easy to make generalisations based on the findings of this work. However, the ability to provide descriptive and explanatory insight into the research topic is a strength of case studies, which was the priority of this research (Flyvbjerg, 2006). This research has used in-depth data collection and analysis methods to reveal a wealth of opportunities and areas for further enquiry into this area, as discussed below.

8.6. A reflection on why regulating, designing, constructing and operating WHV is so difficult in low energy buildings

This section reflects on why the area of WHV is so challenging, based on the results of this study, reading in the area and the author’s personal reflection.

When a naturally ventilated building’s fabric is well insulated, the main form of heat loss is ventilation. In order to meet the UK’s energy efficiency targets, all new buildings need to be close to zero energy.[183] Low energy homes have considerable advantages over older properties: they may be perceived by some residents as healthier and more comfortable, they can be less prone to mould, and they probably generate lower fuel bills than older properties. However, it seems that some of them are frequently uncomfortable in summer, waste energy and have poor IAQ compared with what regulations and designers hope is the case.

Historically, UK buildings have depended on individual room ventilation, for example, windows, vents and local extract fans. These are relatively simple to understand and their presence in the room is usually visible. The move to WHV is a radical change, perhaps even more radical than the transition from individual room heaters to centralised heating systems. Suddenly, residents must deal with something which is hidden and not transparent, and where what happens in one

[183] By 2020 this will be mandatory owing to the EPBD.

room can affect the whole system (e.g. unscrewing an MVHR vent can unbalance that whole installation). This is combined with the fact that many people do not seem to understand what ventilation is or what it tries to do. In winter, ventilation tries to balance conflicting requirements of minimising heat loss while providing appropriate IAQ, neither of which is easily observed by residents as the human body is not good at detecting moisture, the main domestic pollutant. On the other hand, during summer, ventilation is sometimes expected to facilitate a large heat loss to prevent or reduce overheating.

In addition to the lack of understanding of ventilation among this group of residents, it seems that some built environment contractors and designers do not understand it either. They therefore become very reliant on building regulations to guide their decisions. Regulations have historically been guided by a theoretically reductionist view of the problem, by treating ventilation as an optimisation problem and balancing the requirements of minimal heat loss with the control of pollutant levels. There has been little field testing of building regulations, partly because of the expense and difficulty of measuring energy, pollutant concentrations and ventilation rates. Consequently, theoretical regulations, instead of empirical evidence, inform the industry.

Because there appears to be poor enforcement of the regulations and limited understanding by contractors and designers about what they are trying to achieve, ventilation systems may be inadequately installed and commissioned. This may then exacerbated by the fact that the real world is not like the modelled one: i.e. cluttered volumes are much smaller than theoretical volumes used to size systems, ducts are blocked with furniture, occupant densities can be higher, filters are not changed and carpets prevent airflow between rooms. Therefore there may be a risk that WHV is currently under-delivering the rates of ventilation needed, particularly during peak pollution episodes in toilets, kitchens and bathrooms.

The design of domestic ventilation technologies can also limit the ability of residents to ventilate their homes as intended. For example, the lack of features to alert residents as to when filters need changing and subsequent system underperformance may encourage residents to open windows during the heating season. MVHR system designed without a summer bypass mode exacerbate overheating risk and may prompt residents to use electric fans or air conditioning to maintain comfort. The design of air handling units to be completely silent is confusing for residents who are unable to determine whether the system is working or not and therefore may seek alternatives. Conversely, poorly designed and noisy units may be switched off by residents. The possibility of residents becoming confused about how best to ventilate their homes is not helped by the design of ventilation products as 'black boxes', with confusing interfaces and little visual guidance for non-specialist users, e.g. unlabelled boost switches.

There is also an opportunity to improve the design of windows and trickle vents to enable residents to ventilate more effectively. For example, the design of trickle vents to be wall mounted rather than incorporated into window frames, as observed at one of the case studies, led residents to inadvertently obstruct airflows with their furniture and other possessions.

Window design could be improved to include insect screens and rain sensors to enable residents to use more openings during the night and while away from the home.

It is perhaps surprising that more problems with inadequate ventilation were not encountered (e.g. mould). The main reason appears to be that people develop workarounds, for example by using windows, which they intuitively know how to operate and which produce an immediately visible effect. By doing so, they bypass parts of the system at the expense of using more energy. However, since energy use is also difficult to measure or understand, residents may be unaware of the consequences. Those people compiling the building regulations may benefit from considering that the real world is more complicated than theoretical assumptions, and that perhaps more effort should be focused on enforcing the ventilation regulations. Furthermore, it may be possible to provide better education for designers and contractors in the reasons for adopting WHV and on how to effectively incorporate these systems into a well-designed home.

8.7. Future work

A range of possible avenues for exploration in future work are presented below:

8.7.1. Quantitative investigations of ventilation performance

The findings of this research reveal the need for a more comprehensive investigation of the impact of domestic social practices on energy demand. One way of approaching this could be to quantify the energy loss through open windows, by using heating energy consumption data and window sensors. It would also be interesting to estimate actual ‘inhabited airtightness’, to see how likely MVHR is to really deliver energy savings over MEV or PSV, as opposed to the theoretical savings proposed by Lowe (2000), which assume that windows remain closed while the heating is on. It may also be useful to measure the ventilation rate of each system, by using a hood on inlets and outlets in both normal and boost mode. The findings could then be compared with the ventilation rates required by regulations, to see if a system is performing as expected.

Chapter 5 demonstrated the potential of residents to augment the physical fabric of their surroundings as they rearrange a dwelling into a home, which has the potential to interfere with designed ventilation routes. Future work could measure and quantify the impact of furniture obstructions and other alterations made by residents (e.g. blocking gaps under doors, filling the spaces with clutter) on ventilation rates and IAQ. This would rely on an understanding of occupant density and how this may change in the future. Furthermore, there may be scope for conducting research on the impact of low energy design solutions on the use of space. For example, it may be the case that including systems such as heat pumps, water tanks MVHR units and increased insulation (thicker walls) reduces the amount of space available in LEH.

As discussed in section 5.2.1, it appears that the building regulations, SAP and Approved Document F (ADF) may motivate design teams to select a certain ventilation system, without having a clear design understanding of the implications. Further studies of the performance of different systems may help develop more robust guidance based on evidence of what different systems may achieve in practice.

8.7.2. More on domestic social practices

There is still much more theoretical work to do around domestic social practices and energy consumption. This research has revealed an inextricable link between heating, thermal comfort and ventilating practices; however, the connections between ‘bundles’ and activities relating to different types of domestic practices are not yet fully understood and could be investigated further.

While this thesis has focused on two specific readings of SPT (constraint/enablement and the four elements of practice), the literature around the theory provides a plethora of concepts which could be explored empirically in this field. For example, in this study the idea of ‘prefiguration’ was borrowed from Schatzki (2002). However, this is just one of four types of *‘social relations’* which he defines, the others being ‘*causal relations’, ‘spatial relations’* and *‘intentionality’* (p.40). Each of these areas could prove fruitful in illuminating the subject further.

Chapter 7 discussed some examples of how and when people’s activities might change, in order to demonstrate that there is scope for interventions aimed at helping residents adapt to new systems and technologies. A natural next step would be consider how to promote ‘transitions in practice’ (Shove, 2012), so as to guide domestic ventilation practices in a more pro-environmental direction and to accelerate the rate of change. This could be done through a longitudinal study of certain interventions to test out which is most effective. The idea of ‘disruptions’ could be investigated further. The literature of *‘epiphanies, turning points and critical biographical moments’* (Holland and Thomson, 2009, p.451) is often used in the context of more extreme, life changing, events, but perhaps there may be scope for exploring this body of work in relation to the changing dynamics of practice. For example, Hards (2012) uses narrative methods to illuminate *‘”transformative moments” in the lives of individuals who take action to address climate change’* (p.172).

There is also an opportunity to investigate differences in routines, lifestyles and consumption patterns between people of different gender, class and ethnicity. Although work has been done from a psychology perspective in relation to environmental attitudes among these groups (Virden and Walker, 1999, Johnson et al., 2004, Barr, 2007), an investigation of lifestyles and practices would be novel.

8.7.3. Advancing socio-technical methodologies

Studies applying truly socio-technical approaches to this research problem are currently rare. However, this research has demonstrated the suitability of this kind of interdisciplinary approach to the field of energy demand reduction. A more comprehensive socio-technical methodology could combine qualitative methods with monitoring of technical parameters (e.g. energy consumption, internal temperatures and ventilation rates), to understand the environmental repercussions of individual households’ lifestyles more fully. Ideally these studies would draw on the skills of multiple researchers, each with their own deep disciplinary knowledge, to push the boundaries of socio-technical research into practices and lifestyles.

In addition, it may be useful to investigate alternative qualitative methods, such as resident observation (e.g. Pierce et al., 2008), filming of certain activities (e.g. Bailey et al., 2013), and activity diaries (e.g. Crosbie, 2006), to capture the rhythm and nuances of daily activities which more conventional methods such as interviews may miss.

8.7.4. Exploring 'communities of practice'

The main units of analysis in this thesis were the domestic ventilation practices of residents. However, the research also touched on the activities of various other actors involved in the design and construction of homes. This could be developed further to centre the investigation on the design, construction and management practices of architects, contractors and RSLs respectively, in order to understand more fully how these professional practices overlap and intersect with domestic practices. In addition, talking to building control bodies and planning authorities to explore the processes by which compliance with building regulations is assessed (e.g. checking whether mechanical systems have been commissioned correctly) may have proven informative. There is call for expanding understanding in this area in the literature. For example, Balvers et al. (2012) point out that the '*lack of coordination between the design team, the engineer and the installer, leading to contradictions on site that result in compromised installations'* (p.13).

The communities of practice (CoP) concept is used by Wenger (2000) to explore how learning takes place within groups of people with shared interests, goals and experiences. As well as connecting individuals through a shared repertoire of knowledge and tasks, communities of practice can also exclude others, for example through use of specialist vocabulary or by requiring certain qualifications to participate. This research has revealed gaps in communication between various members of the building industry, particularly around the handover of domestic ventilation technologies to building users, but also in relation to the selection and specification of appropriate systems. More research into professional organisations, structures and processes could provide insight as to how residents' actions are being constrained and enabled by design targets, regulations and industry standards.

Heaslip (2013) offers a critique of Janda's much-cited maxim that *'buildings don't use energy, people do'* (Janda, 2011), arguing that this can be used by the construction industry to try to relinquish their influence on building performance. Instead, responsibility for final energy use should be shared across arrangements and industries, and good designers should seek to anticipate and understand the lifestyles of building users so that the built fabric enables residents to live a sustainable life. This needs a whole new area of research if the industry is really keen to make handover work.

8.8. Conclusion

This thesis has explored how residents of low energy housing (LEH) with WHV technologies are ventilating their homes, and found that while some ventilation practices may have adapted since the residents started living with WHV, this process of change is slow and unpredictable, and is not always aligned with designers' intentions for sustainable lifestyles.

Currently, WHV is not widespread in British dwellings, which are traditionally characterised by a leaky, naturally ventilated building envelope. However, WHV systems are being introduced into new housing as a way of improving the energy efficiency of the UK's housing stock. WHV comprises components such as heat exchangers, fans, ductwork, switches, sensors and filters, many of which are not found in older housing. Although it is hoped that these technologies will provide fresh air in airtight dwellings whilst reducing energy demand, the findings of this research question such technological determinism, prevalent in buildings research, which assumes that new technological interventions will somehow stimulate change by themselves.

Instead, to fully realise the potential of WHV in terms of energy and indoor air quality (IAQ), inhabitants will need to change the way they ventilate their homes too; technologies by themselves may not create this change. The design of LEH with WHV anticipates different ventilation practices compared with a traditional home. For example, filters need changing, boosters activating and vents cleaning; furthermore, it is also expected that windows are manipulated and reconfigured by the resident to prevent overheating and facilitate ventilative cooling during hot weather. If people do not adapt the ways they ventilate, but continue to use traditional strategies such as opening windows, low energy homes may use more energy than expected, contributing to the 'performance gap' between designed and actual energy use.

This thesis adds to the growing body of discourse around practice theory and energy consumption by focusing on a particular set of technologies and associated practices, and by extending the scope of the investigation to the design and construction team, who have previously been largely omitted from the discussion of residents practices. Rather than blaming residents for inappropriate 'behaviour', it is hoped that this investigation of both practices and spatial configurations will contribute to an enhanced understanding of the ways people adapt to living with innovative ventilation technologies and some of the consequences that this may have on domestic energy use.

The research reveals that socio-technical arrangements, comprising occupants and design teams, as well as the physical configuration of the dwelling and its ventilation components, may both constrain and enable the way a home is ventilated. In some instances, these arrangements were found to be preventing occupants from ventilating in the way designers imagined they would; this may explain why the homes are prone to overheating and why residents are resorting to the use of electric fans and other active cooling systems. This could reduce the success of LEH in terms of both energy use and IAQ.

It was also found that ventilation is 'practiced' by residents through the routinised performance of dynamically connected clusters of embodied routines, conventions, meanings and objects. These relate to a host of activities related to providing and maintaining a comfortable, safe and healthy home environment. The importance of past experience on people's lifestyles was also discussed. While residents sought to make sense of the WHV as best they could, many were confused about what the technologies were supposed to do, how they worked and what, if anything, they, as occupants, should do to operate the equipment and to prevent problems. On a positive note, most of the residents were satisfied with their new homes and many felt that they were an improvement over their previous accommodation, suggesting that some of the potential benefits of new LEH are being realised.

Some of the interactions between the residents and the professionals involved in designing, constructing and managing their homes were analysed and discussed. These interactions, frequently occurring as a result of POE work, are not only of benefit to the professionals; for residents, they constituted 'disruptions', moments when their awareness of otherwise hidden components relating to the ventilation of the home were temporarily raised. These events may have the potential to be leveraged to enable residents to develop more sustainable ventilation practices, although the slow rate of change may be of concern to those wishing to see rapid changes to mitigate against the time-limited threat of climate change.

The thesis concludes that the mechanisms by which occupants' ventilation practices are shaped during the design, construction and handover of new LEH need to be considered in order to ensure that new homes can enable, and perhaps even encourage, people to live comfortably yet with minimum resource use. Only this way does WHV have the potential to play an effective role in the decarbonisation of new housing in the UK.

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A SOCIO-TECHNICAL PERSPECTIVE OF VENTILATION PRACTICES IN UK SOCIAL HOUSING WITH WHOLE HOUSE VENTILATION SYSTEMS; DESIGN, EVERYDAY LIFE AND CHANGE
Volume II Appendix

Carrie Behar

April 2016

UCL Energy Institute

A thesis submitted in partial fulfilment for the degree of Doctor of Philosophy

Appendices

Participant Pseudonyms

The following pseudonyms and dwelling codes are used throughout the text (especially Chapters 5-8). Readers are advised to refer to a copy of this page for reference.

Participants	Pseudonym (code)	Case	Ventilation type	Profession / role	Dwelling code
Residents	Ali	A	MEV		A0
	Sabeen	A	MEV		A1
	Fara	A	MEV		A2
	Karen	A	MEV		A3
	Pamela	A	MEV		A4
	Betty	B	MVHR		B0
	Paul	B	MVHR		B1
	Dan	B	MVHR		B2
	Anthony	B	MVHR		B3
	Steve	B	MVHR		B4
	Luke	B	MVHR		B5
	Carla	C	PSV		C0
	Sarah	C	PSV		C1
	Maria	C	PSV		C2
	Joy	C	PSV		C3
Non-residents	Christopher	A	MEV	Project Architect /Director	
	Richard	A	MEV	POE Consultant	
	Eddie	A	MEV	RSL - Sustainability Manager	
	Yvonne	A	MEV	RSL - Sustainability Officer	
	Mark	B	MVHR	Project Architect / Planning Stage	
	Dominic	B	MVHR	Project Architect / Construction Stage	
	Stuart	B	MVHR	Contractor - Design & Planning Executive	
	Janet	B	MVHR	RSL - Housing Officer	
	Brian	B	MVHR	RSL - Project Manager	
	Helen	C	PSV	Architect - Partner	
	Martin	C	PSV	Contractor - Director	
	Michael	C	PSV	RSL - Technical Manager	
	Douglas	C	PSV	RSL - Business Manager	

Appendix A. INTERVIEW ADMINISTRATION

Appendix A.1: Interview prompts

A series of prompts were developed to be used during interviews. During the test interviews, a piece of paper with various words and phrases related to the research questions was presented to participants, who were then asked to describe what they understood by each of the terms (Figure 58Figure 62). After the first two interviews, one participant suggested that the hexagons could be presented in smaller clusters, to make the connections more obvious. However, this could be problematic as it would predetermine which variables are interconnected and how, rather than leaving the test open to the interviewee to make their own connections. The task was adapted to use individual cards, shown one by one to the respondent. First, they were asked what they understood by the word or phrase, and then prompted to arrange them in a way they felt appropriate (Figure 59 and Figure 60). The figures show two different configurations of cards arranged by a participant. Although this activity created an interesting opportunity for further discussion, it was found to be rather time-consuming (a few residents complained about the duration of the interview) and not all that conducive towards answering the research questions which evolved over the course of the fieldwork. Furthermore, as the researcher’s confidence grew it was no longer felt necessary to provide physical prompts for conducting interviews. The activity was not continued into the second year of fieldwork, although data collected during the preliminary interviews were coded and analysed as part of the study (the voice recorder continued to run during this part of the interview).

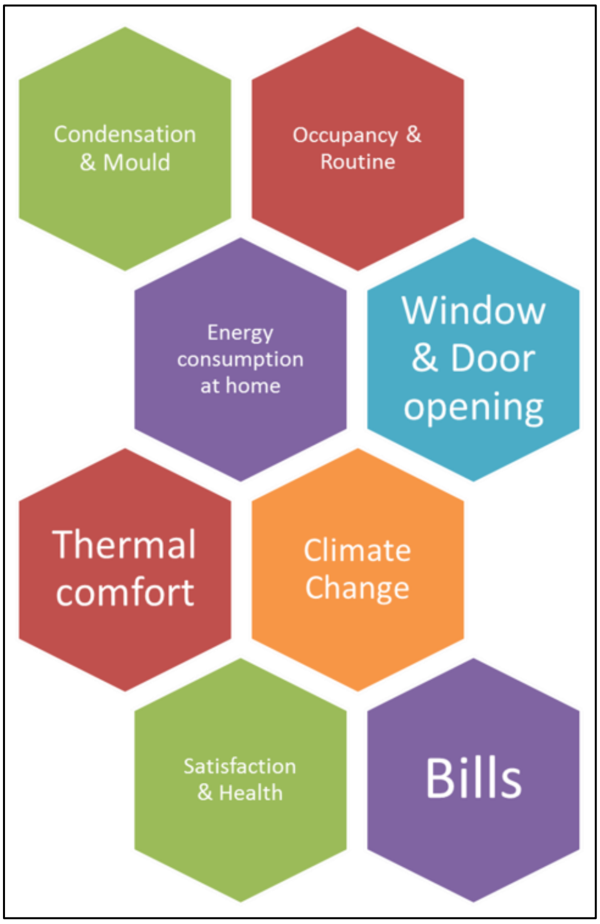

Figure 58: Initial knowledge test layout

Figure 59: Arrangement of cards during test interview

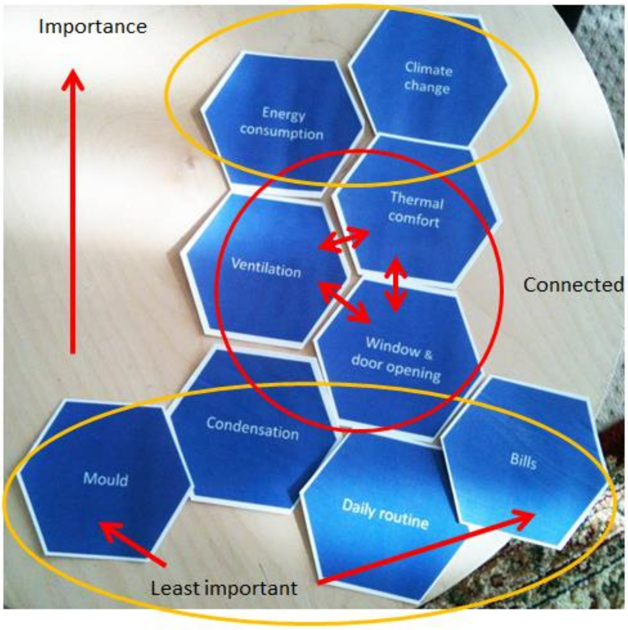

Figure 60: Arrangement of cards during preliminary fieldwork

Appendix A.2: Consent form and information sheet

Low-energy Housing Interview Consent Form

	Please tick
I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions.	☐
I understand that my participation is voluntary and that I am free to withdraw at any time, without giving reason.	☐
I agree to take part in the above study.	☐
I agree to the use of anonymised quotes in publications	☐

Name of Participant	Date	Signature
Name of Researcher	Date	Signature

Contact for Further Information

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By completing and returning this form, you are giving us your consent that the personal information you provide will only be used for the purposes of this project and not transferred to an organisation outside of UCL. The information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection Act 1998.

If you have any concerns about the way in which the study has been conducted, you should contact the UCL Research Ethics Committee on 020 7679 7844

Thank you for taking the time to read this information sheet.

Figure 61: Participant consent form

Low Energy Housing Interview Information Form

You are being invited to take part in a research study. Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully.

What is the purpose of the study?
We have been asked to look at how your use of the home might affect its energy efficiency and resource use. We are also interested in what you think about your home in terms of its performance.

Why have I been invited to participate?
You have been chosen to participate in this study as a volunteer recruited by Carrie Behar and Charmaine Willoughby.

Do I have to take part?
It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason.

What will happen to me if I take part?
You will also be asked to complete one interview and to take part in a walk-through around your home.. The interview/walk-through will take no more than 1 hour maximum. The walk-through will consist of the researcher accompanying you on a tour of the house together with other members of your family or household, giving you a chance to point out any issues.

What are the possible disadvantages and risks of taking part?
Taking part in this study involves the time taken for completing the interview and walk-through

What are the possible benefits of taking part?
By taking part in this study you will contribute towards understanding how we can reduce the current energy use savings in UK dwellings without compromising health and comfort. You will be fully informed of the outcomes of the study which will also help you to understand how your house works best.

Will what I say in this study be kept confidential?
All information collected about you will be kept strictly confidential (subject to legal limitations). Names and addresses will be anonymised. Anonymised data generated by the study will be retained by the UCL Energy Institute.

What will happen to the results of the research study?
The results of the research study will be written up as part of Carrie Behar's PhD thesis, who may see fit to publish extracts from it. Research papers on particular aspects of the study may be published in reputable academic journals. If you would like copies of these please contact Carrie Behar in the first instance (details above).

Who is organising and funding the research?
Carrie Behar is conducting the research as a PhD student at UCL. The research is entirely funded by the EPSRC: http://www.epsrc.ac.uk/Pages/default.aspx.

Who has reviewed the study?
The research has been approved by UCL.

UCL

Figure 62: Participant information sheet

Appendix A.3: Example interview schedules

MEV Introduction

'Thank you for taking part in this interview. I'm doing a PhD research project at UCL and this interview is a part of my work. I'm going to begin by asking you some general questions about the house and then go on to some more specific questions which relate to my research area, which is looking at ventilation and low energy housing.

If you agree then I would like to record our conversation with my voice recorder. The recording will only be listened to by me and my supervisor and it will be totally anonymous (so I won't share your names and addresses with anyone). I may use quotes from the interview in my written documentation but again these will always be anonymous.

Before I begin I'd like to ask you to sign this consent form, which states that you understand what is happening and are happy to go ahead with the interview'

So I'll begin by asking you a few general questions about the house.

Warm up

- Could you start by telling me how long you've lived in this flat and who else lives here?
- Could you tell me a bit about how you chose to live in this particular flat?
- Could you tell me a bit about your previous home?
- How do you feel about this dwelling compared to your previous dwelling? (likes/ dislikes?)

Ventilation System

- I'm particularly interested in the way people ventilate their homes: Could you tell me a bit about how you ventilate this flat?
- Please could you explain to me how the ventilation system works in this flat?
- So could you explain to me what you'd do to get fresh air into the rooms? (windows, boosters?)
- How do you feel about the ventilation system installed in your dwelling? (likes/ dislikes?)
- Could you tell me about what the air quality is like in this flat?

Windows and Doors

Now I'd like to talk a bit about how you use the windows at home.

- First of all could you tell me when you might open the windows in this flat?
- And when might you close them? (rou*tine/ daily? Particular events?*)
- Could you tell me when the last time you opened a window was?…
- Would you ever open windows and doors at night?

IAQ

I'm really interested in finding out if your home is getting enough ventilation and fresh air

- In your opinion, does you ventilation adequately remove any smells or moisture from the kitchen and bathroom?
- I was wondering if you ever notice condensation on the windows? or lots of steam?
- What about cold or damp patches on the wall? Any cracks or black bits? What about mould? (If yes then what have they done about it?)
- Could you talk a bit about whether you've ever had these kind of problems in a previous home? (If yes - then ask for details)
- Could you say a bit about whether you've ever had any health problems which you think might be caused or made worse by living here? (smokers or pets?)

Operation and maintenance

- Has anyone ever offered you any advice on how to use the ventilation in this flat? (If yes, what form did it take? (Did you get a manual? Was it helpful?)
- How well do you feel that you understand the operation of the ventilation system installed in your dwelling? (Can you tell if working or not? How?)
- Do you use the boost switch to control the ventilation? (When? Why? How often? Does it work?)
- Could you talk a bit about if there are any difference in the way you ventilate at different times of year? (summer bypass mode?)
- Could you talk a bit about any maintenance that the ventilation needs? Have you ever cleaned the extracts or changed filters? Has anyone else?

Thermal Comfort

I'd like to find out what it's like in this flat and whether it's a comfortable place to live

- Could you talk a bit about the temperature in the flat? (different times of year?)
- Heating system - controls? Programme? Thermostat? Instructions?
- Satisfied with thermal environment? Draughts? Too hot or too cold? Overheating?

Bills

- I was wondering how your utility bills compare to your previous home? (how do they pay?)
- Who pays the bill? Do they know how you pay for gas and electricity?
- Would you say that you actively try to reduce the cost of these bills?

Sustainability

I'd like to find out what you think about issues such as the environment and sustainability?

- Are you interested in energy efficiency / saving? Why? What do you do about it?
- Are you aware of climate change? How does this affect your life?
- Would you say you actively lead a green lifestyle (recycling, ride a bike, public transport, switching off lights?)

Wrap up

- Thanks for answering those questions; before we move on is there anything else that you'd like to mention about what it's like living here?
- Or anything you'd like to ask me?

Wrap up

- Thanks for answering those questions; before we move on is there anything else that you'd like to mention about what it's like living here?
- Or anything you'd like to ask me?

Walk-through

Prompts

- *Could you show me how to open your window please? When would you do this?*
- *Check for extract hood above cooker*
- *Check for electric fans*
- *Check for mould / damp*
- *Check which windows are open and if heating is on (thermostat setting)*
- *Could you explain how this works…*
- *When would you use this…*
- *How often would you….*

Figure 63: Example resident interview schedule (3 pages, Case A)

Introduction

'Thank you for agreeing to take part in this interview. I'm doing a PhD research project at UCL and this interview is part of my research into domestic ventilation technologies in low energy housing.

I'm going to begin by asking you some general questions about your involvement with the ~~{name}~~ project - in particular blocks B and C. Then I'd like to talk in a bit more detail about the mechanical extract ventilation that was used in the project. Please don't worry if you're not sure how to answer any of the questions or if you can't remember something. It's not a test and I'm equally interested in your opinions and views on any of the topics we cover.

If you agree then I would like to record our conversation with my voice recorder. The recording will only be listened to by me and my supervisor and it will be totally anonymous (so I won't share your names and addresses with anyone). I may use quotes from the interview in my written documentation but again these will always be anonymous.

Before we start I'd like to ask you to sign this consent form, which states that you understand what is happening and are happy to go ahead with the interview'

So I'll begin by asking you a few general questions to jog your memory about the project.

- Please could you tell me a bit about your involvement in the ~~{name}~~ r project?
- What were the design aspirations of the project?
- Were there any specific design or sustainability targets you were aiming to achieve?
- What do you think was the most successful aspect of the project?
- Is there anything you would do differently in hindsight?

Design of ventilation

- Could you tell me a bit about the ventilation strategy at ~~{name}~~? (Why MVHR chosen and by whom, at which point in design process?) How did this relate to the fabric strategy?
- Could you tell me about some of the things you would consider when choosing a domestic ventilation system?
- Please could you explain to me how the ventilation works? (fan units, ceiling vents, which model?)
- Could you tell me about your previous experience with MVHR? (so is this system unique? Or is it similar to something you've used before? Have you used it since?)
- Please could you describe in a bit more detail the system that was specified at ~~{name}~~? How were the technical drawings prepared? (by whom? At what stage?)
- I'm interested in what modelling and simulation techniques were used to inform the design of the ventilation system? Could you tell me about the simulation process? For example do you find SAP a useful tool?
- I'm curious about how this configuration came about (Is there a particular reason why the main fan unit placed in the cupboard? How about the positioning of the boost switch?)
- I'm interested in whether the design of the windows relates to the ventilation strategy in any way? How? (Was the layout of the spaces affected by the choice of ventilation system?)
- Could you tell me a bit about what kind of maintenance this kind of ventilation needs? What would happen if not carried out?

Construction

- Could you tell me a bit about your involvement in the project during the construction phase?

Commissioning and handover

- Could you tell me a bit about your (practice's) involvement at the commissioning and handover stages?

In use

- Have you had a chance to visit the properties since the residents moved in? What was your impression of the dwellings? (i.e. is he satisfied / pleased / disappointed with how the project turned out)
- Have you any information about how the residents of the dwellings have responded to the ventilation system? Issues? Other feedback? What about management?
- Could you tell me a bit about how you think the residents are ventilating their homes?
- And (how) would this differ in a home without a mechanical ventilation system?
- At what times do you anticipate that they would interact with some part of the ventilation?
- I'm interested in what kind of information you think a resident needs to live comfortably in a dwelling with this ventilation system?

Appointment to do up to planning only

- Is this something they do often? Pros and cons for the project?
- What effect (if any) do you feel this arrangement has on the competed project? M&E, Handover, Who is responsible for what?

Ideas about Ventilation

My thesis is about ventilation so obviously I'm very interested in the subject, but I'm wondering what your thoughts about ventilation are?

- I'm interested in your opinion on why we should be concerned with providing good ventilation in homes?
- Could you tell me about what you feel the most important purpose of a ventilation system is?
- Have you / would you consider using MVHR in subsequent projects? Why/why not? Modifications?
- Could you tell me a bit about the benefits of using MVHR in homes (to the design team, the client, end user..)
- Could you describe to me some of the ideal criteria for a property that would suit this system?
- Please could you tell me what kind of ventilation you are used to living with?

Ideas about Sustainability

- I'm interested in your feelings about environmental issues and sustainability in architecture?
- Please could you tell me what you think are the key components of a sustainable home? (i.e. how can we tell if a home is actually sustainable?)
- According to you definition, how sustainable do you think the homes at ~~[name]~~?

Thank you very much; that's the end of the main part of the interview. Is there anything else that you'd like to mention or that you think would be useful for me to know or people you think I should speak to?

Does he have a contact with:

- Contractors
- engineers (M&E)

Figure 64: Example non-resident interview schedule (architect)

Appendix A.4: Research ethics

According to Diener and Crandall (1978), the most important ethical consideration for researchers is to protect all participants, including themselves, from harm. Secondly, the research community must always strive to develop a trusting relationship between academic institutions and the wider public, in order to enable future positive collaborations (Jorgensen, 1971, P.327). The following six fundamental principles of ethical social research have been identified by the Economic and Social Research Council (ESRC, 2010):

- Integrity and quality
- Fully inform researchers and participants
- Confidentiality and anonymity
- Voluntary participation, free from coercion
- Avoiding harm
- Independence and impartiality of the researchers

There were three main ethical and best practice concerns relating to this project: Firstly, how to maintain the privacy of the 'residents' group of research participants, while at the same time allowing them the opportunity to feed back to management on any issues they were facing? Secondly, how to maintain the confidentiality of research participants who were professionally connected to the case studies (e.g. architects, RSLs, and contractors)? This was particularly challenging given that the community of professionals working within sustainable housing design is small and several of the participants may know each other, and they certainly all have mutual contacts. Thirdly, how to ensure the safety of the researcher when working in the field and while visiting private homes?

The steps taken to address these concerns are outlined below with respect to ESRC's six principles.

Fully informed researchers and participants

An information sheet was given to each participant at the start of each interview. This outlined the purpose and format of the study, with a brief explanation of the potential risks and benefits of taking part. The information highlighted the voluntary nature of their participation, the opportunity to withdraw at any time and also provided the researcher's contact details for any follow up enquiries. Sufficient time was allowed for participants to read the form without pressure. Any questions were answered clearly and truthfully (Figure 62).

Confidentiality and anonymity

In some interviews residents were keen to raise concerns about their living arrangements. When this was felt to be the case residents were asked if they would like information to be passed onto the RSL on their behalf. This was requested after one interview (Carla) where the resident was clearly distressed at her circumstances and asked the researcher for help.

The greatest challenge was faced when conducting interviews with RSLs, half of whom (3/6) were on first name terms with each of the residents who had been interviewed and were keen to share anecdotes relating to individual residents. In this situation the researcher had to be careful to protect the confidentiality of the resident without disrupting the flow of the interview.

Participants currently working in the construction industry were more concerned about their anonymity than other participants. One participant requested that he be consulted before any quotes are published in academic papers or public domain reports. It was decided that this was a sensible strategy for all professional participants who may risk damage to their reputation were their comments publicly attributed to them.

Voluntary participation

All participation was voluntary and free from coercion. Residents were first contacted by letter, with a second follow up request made either by telephone or in person. If they were not keen to take part their decision was respected and no attempts were made to talk them into it against their will. All participants were asked to sign a consent form after reading the information sheet. A copy of the consent form, completed by each of the interviewees, is included in Appendix A.2: Consent form and information sheet (Figure 61). The non-resident participants were generally happy to help but were understandably more concerned about confidentiality and anonymity, as discussed above.

Avoiding harm (safety in the field)

Preliminary interviews were arranged with help of RSL housing manager at all three sites with residents who were well known to them and trusted. In all three cases the housing manager attended the start of the interview to make the introduction between the participant and the researcher. This reduced the risk of harm to both researcher and participants.

The following year, fieldwork was conducted alone, with less input from the RSL. However, this was felt to be acceptable as the areas were by now known to the researcher and deemed safe. However, as one-to-one interviews with residents were conducted with people in their own homes, on a subject that can occasionally arouse strong feelings (as could any conversation about everyday practices which are, ultimately, quite personal things) a strategy was put in place to ensure the safety of the researcher. A colleague of the researcher was informed of the time and location of the interviews and contacted before and immediately after each interview. They were instructed to raise the alarm if they did not hear from the researcher within a fixed period and were not able to reach them by phone.

Integrity and quality

The project was registered with the UCL Data Protection Officer (Z6364106/2012/01/33). Ethics approval was not required for this project as all data was being collected with the full approval and informed consent of the participants. Personal information (names and addresses) was removed from the interview data and stored separately.

An ethical piece of research does not just avoid harm and misconduct, but actively seeks to do good. Israel and Hay (2006) state that doing social research can *'impose duties and obligations* *on the researcher to act to the benefit of participants'* (p.100). As well as feeding back residents' concerns to the RSL, steps were taken to disseminate the findings of the research to the wider community, both academic and in industry. To this end, three presentations were made at leading architects' practices.[184] Anonymised findings were also presented at one of the RSL's trustee meetings as a way of sharing the findings with the organisation who had voluntarily contributed their time and resources towards the project. In one case a resident was contacted by telephone after the interview to clarify a question he had had about the cost of running MVHR which the researcher had not been able to answer at the time.

Independence and impartiality of the researcher

The researcher has no undeclared conflict of interest in this work.

[184] Payment of £100 was received for one of the sessions.

Appendix B. DATA MANAGEMENT AND ANALYSIS

Appendix B.1: Post-interview memos

Memos were handwritten immediately after conducting the interview and then typed up later:

Ali

He was very chatty and seemed well educated and knowledgeable. His wife was present and seemed more reserved. I didn't feel able to speak to her (interview lasted 1.5 hours with Ali so I felt like I had been there a long time). After I stopped recording we spoke a bit more and also went into the downstairs shower/WC and spoke about how they removed the metal grating on the shower as mould was growing. The fan on the wall looked quite dusty. I asked if they ever clean it and her said 'no' and asked if I thought there might be a filter. I said I wasn't sure. We then decided to try and press the grey button on the unit to see if it was a boost. I tried to climb onto a plastic stool on the shower but it was wobbly so I used a broom handle to try and press the button. It didn't work so we concluded that it probably wasn't a button.

Sabeen

Relatively middle class - aspiring to get on the property ladder. Very talkative and helpful. She told some interesting stories such as the one about the kids changing the thermostat settings and also not being able to open windows after dark for fear of letting lots of bugs in. She can't seem to get to grips with the thermostat timer and prefers to do things manually. This is a home that seems to be occupied for much of the time as dad works nights. Quite interesting how they leave the pole for opening the rooflight open all the time - good because they won't lose it but perhaps a bit dangerous. Also interesting that her house does seem to be very prone to overheating - is this because of its microclimate and orientation? or the fact that they are not opening windows when it is cool and not seeing the effects of ventilative night cooling? Interesting that her husband's losing his hob was a trigger for them start saving energy - the financial shock seems to have made them more aware which may lead to new habits being formed? Also interesting that they do not use the high level windows in the living room (either side) which is something that may help with cross ventilation?

Fara

The adults in this family do not speak much English (They are from Pakistan). Dad a little, mum virtually none. The daughter who translated was interesting but quite often answered the questions directly instead of asking her parents. Also, dad was sitting on the other side of the room so not sure if his comments will be audible. There are about 11 people living in the house and I got the impression that someone is in the house most of the time. They never use the rooflight above the stairs and have windows open a lot. She said the house was nice and cool in the summer but they use fans in all the rooms so I'm not sure what it would be like without. Interesting how she said that the rooflight in the bedroom created a lovely breeze but that they choose not to use the rooflight above the stairs and seem to use fans quite a lot. Especially as they described themselves as 'poor' which no one else has done so far. The prayer clock was fascinating; it goes off when it's time to pray but it also displays the temperature (as well as the date and some other features - it's digital). She said that it always read around 21 degrees even when they moved it around and tried it in other rooms. There may be a lot of noise on the recording as the smallest child was talking and crying a lot and also trying to pick up the voice recorder.

Karen

Friendly woman. Probably what [RSL] would describe as a 'model tenant'. Amazing that she'd lived there for 6 years before finding out about the MEV AHU in the attic when the RSL realised that they need maintenance and sent someone round. Also interesting that [RSL] didn't realise that they needed to do any maintenance for all that time; I wonder if [Eddie] or [Christopher] mentioned this at all in their interviews. This is one of the homes with bad overheating (though it's good to hear that the 31 degrees that [Yvonne] mentioned was due to a sensor being placed near a light fitting!). There was a good bit at the end when she spoke about when the architect came round to visit and was please that they were happy. I felt like she was the most relaxed at this point. Does recycling but not that bothered about the environment. I didn't probe why she was so keen on the recycling which is a shame. The inlets were covered up and blocked in several rooms which probably isn't helping. It was already pretty warm and the interview was conducted on a mild day with no sun. The dog is interesting - reminds me of Tadj's comments about how opening the back door for dogs is a big user of energy. But in this house the issue seems to be more to do with the high electrical load. As she mentioned there are a LOT of electrical gadgets in the house: TVs in several rooms, hi-fis, radios, games consoles and lots of white goods. She uses an electrical fan at night during the summer and is considering buying a Dyson AC fan. While we were talking she opened the back door as it was warm in the room (she explained this because the tumble dryer was on) and then she closed it again because it was windy and the curtain was billowing into the LR. Another reason she implied for closing windows seems to be security (downstairs) as well as rain coming through the rooflight. The boiler cupboard was great! Completely blocked with storage. They found the thermostat manual more useful that the verbal instructions - good news that the manual was useful.

Pamela

This residents was friendly and seemed quite open and relaxed. She is not totally satisfied with the house and is looking to move quite soon. Partly because it's time to downsize a bit but also because she has some issues with the house. These include the fact that it is too cold in winter and too hot in summer and the utility bills are not actually lower than in her old place. Her daughters were around during the interview with a small child (granddaughter I assume?) who was screaming and running around quite a bit so there may be some interruptions. When we walked around the most concerning thing was that the boost switch doesn't seem to be working properly. Also, it doesn't seem like this property has had its MEV filter changed which might explain why it's not performing as well as she thinks it needs to.

Betty

She couldn't hear the MVHR fan in the cupboard, although she did seem to be able to hear it when she'd pressed boost. It was very hard to probe her on concept of fresh air (although did I ever mention air?) She was more interested in the heating and the novelty of having radiators than the ventilation. My thought: When it's working properly, ventilation is taken for granted, the other two places experienced problems, and therefore had much more to say on the subject. After I'd stopped recording we went round taking photos. I took a photo of the boost thing (gizmo she called it) and she noted that it was still on since she'd showed me earlier *'see? I switch it on but not off'* and I wondered if this was something she'd heard from lighting campaigns. Absolutely no interest in environment, climate change or global warming. She doesn't seem to pay many of her bills so perhaps saving money is not a huge priority, although she did mention that she's paying more or less the same as in the old place for her utilities (excluding water).

Paul

Guy lives alone. Heavy smoker, smoking during interview. Took a bit of time to get going but definitely warmed up towards the end. Was quite interested in saving money on the heating - he seems to have quite high energy bills. Higher than in his previous place. After I stopped recording we went into a bedroom to test whether the MVHR was blowing. I held up a piece of paper and not much happened but when I climbed up onto the bed and put my hand up I could feel the air moving. He got up too and was quite surprised to feel a little bit of air although he didn't feel it was that much. He also mentioned his son being an electrician and having a look at it and saying that he had never seen one of them in a home before. He told me that he did Psychology at Uni but didn't like the statistical analysis bit so he got his brother who was a maths teacher to help him with that bit. I was interested that he was adamant that he liked to breathe as well as evidently being a heavy smoker. The windows were open on the latch setting. He showed me how he'd open the latch to open it wider if need be but usually left them on the latch. Another example of windows open and heating on. Experience of mould in old home. Seems generally happy with new flat despite not really having any real choice about where to live. Very tidy house with not much stuff in it. TV was on standby with light on. Doesn't really care about environment - says it's because he's selfish but also clearly reads quite a bit and has noticed messages about climate change. Seemed intelligent and well read. 2 year cooker hood thing is interesting.

Dan

Technical guy. Had read the manual but couldn't remember much else - suggested that they had a separate ventilation leaflet (this sounds true as corresponds with [Janet]'s comment about writing to them about the cost of running the MVHR and asking them not to switch it off).

Interesting that he told me after I'd stopped recording that he did property maintenance for a living (though not heating and ventilation - more fixing stuff and cleaning gutters etc.). He lives alone - could be a guy who actually reads the manual and worked it out from there. He seemed a bit reluctant to get going and had his arms crossed for the first part of the interview, although I think he relaxed a bit towards the end. Windows were all closed but he suggested that was because he had only just woken up and because he was ill. Phobia of spiders - not ideal as he does maintenance work! Door to MVHR cupboard obstructed. He believe you could adjust the vents to adjust the flow - he said he'd never done it but I wonder where he got that idea from. Surely that would unbalance the system? Doesn't sound like much maintenance is being done. [Block 1] is the RSL housing so I should ask [Janet] about this. Have they had the boilers serviced? [answer: yes - it sounds like this is because of the legal requirement - [Janet] mentioned being sued several times I think]. Are all the residents still the first resident or have there been some changeovers? Interesting attitude to environment and climate change. Not too bothered but does his bit (recycling bin in the corner of the living room in a prominent place - see photo of my sketch in my notebook showing position of bin). Thermostat cracked so he can't see if the timer setting is on. It's been like that since he moved in so that's why he controls the heating 'manually', which just seems to mean turning the temperature up and down. Doesn't sound like he ever uses the on-off boiler switch - so that would again mean heating running and windows open and MVHR. I wish I'd asked him why he opens his windows. He thinks the MVHR is working. I think it's hearing the noise when the boost is on that gives him this impression but I'm not sure. He had some pictures on the wall. Nice tidy flat. Not much stuff. Big TV - his 'one joy'. GF flat - interesting in terms of security. He has the window open a wide-ish amount (~22 degrees). There is also an 'open a crack' setting but he doesn't seem to use this). He supposed this would be more for night time and he doesn't like to leave the window open at night because of security and spiders. Check this - temperature seems good. I wonder if orientation has anything to do with this.

Anthony

First time in social housing. Had a swimming pool in his old place so heating bill down from £3000 to £300 or so. His wife was there in the kitchen at the start and then in the bedroom but she had to go out. I wish I'd asked him who it is who opens the windows and who closes them. Interesting that he uses noise as feedback as to whether it's working or not - seems to be a theme. No problems with mould or condensation, good thing. He'd lived with this system before. Even though he seemed to have read the manual fairy carefully he didn't really understand the ventilation properly - thought that all the vents were 'dual function' i.e. inlets and outlets. I told him I'd find out about the summer bypass mode and let him know so I should call Titon / check the spec. Another one just using the thermostat to control temperature - the sofa was in the way of the boiler cupboard so no way to get in regularly and turn in on or off (see photo of my sketch). Not at all interested in environmental stuff. Windows open and heating on and MVHR running. Sounds like no-one ever told him to leave the windows closed (I can confirm this further to conversation with Janet who told me they were instructed not to tell the residents anything about their home and therefore weren't allowed to market it as eco- or energy saving).

Steve

Very dyslexic man. Found it hard to write. I helped him with the BUS. Heating off and switched off boiler even when not using water. Said he was tight. Handover pack useless because a) he struggles with reading and b) his dad died and his partner left him at the time he was moving in so other things on his mind. He got very upset talking about the affair that his ex had so I couldn't really develop the handover thing much but it sounds like he didn't take much in. It's interesting that the windows are open. He knows about the MVHR and calls it the MV although he didn't say this in the interview. At the very beginning he showed me the AHU and explained the noise it makes. Asked me to stand there and then switched the boost on to demonstrate the noise, especially in the bedroom which is right next to the cupboard. I forgot to check the bathroom for mould.

Luke

Very young guy. Quite shy and hard to engage in conversation. He was trying to be helpful but didn't know what to say. Not using booster - keen to save heat. laid back attitude - not too bothered. He was wearing a -t-shirt which said [...]. Didn't spot the first word as he had something over the top but I wondered if it was the same place as R_4 worked. Messy cluttered flat. Cooking dinner while we spoke (something in the oven) and it smelt a bit burnt.

Carla

Missing.

Sarah

Leaves windows open a lot. Didn't know how PSV works. After I stopped recording I took a picture of the information manual they were given and she said she'd read it 5 years ago and not looked at it since but that she was going to have another look as soon as I left. She had an Owl monitor and an aerator tap attachment in the kitchen. They were provided recently by [local council] who were doing some sort of green advice (sounds a bit like green doctor?) but she was a bit cynical and said it was just [name removed] in the run up to the election. The Owl is in a photo but I forgot about the tap. She was quite eco-conscious. Female, in her 50s, had children. I'm not sure if she worked-- seemed to have a physical disability perhaps due to her trauma. Very kind, obviously devoted to her family-- cooks a lot. At home a lot? I didn't actually ask but that was the impression I got. The ventilation seems to be working okay but then with the windows open it's hard to tell if that's the PSV. She cleans it-- but as there are no boosts she has little interaction with it. Interesting that the info pack says to leave trickle vents open all the time but she suggested that they would be closed in the winter. I guess they are using the windows instead.

Maria

Heating patio with electric heater-- fan on and window open in kitchen - with the heating set on 25! And it's a nice sunny day today. Very friendly and nice woman. Considerate - thinks about the planet and her children. Her son has a green team at school and tells them to switch off lights at home which is interesting. Her place doesn't seem to have much overheating. I wonder of its geometry is different from the others in terms of shading? It's only a two storey place and the surrounding ones may be taller and block out the sun? Or maybe it's because they are from [country with tropical climate] and are used to hot weather (though it might be cold in some parts of [country with tropical climate]?) She was very agreeable - she never had anything negative to say and I wonder if that's because she's a positive person or whether she wasn't that able to relax. It was also quite a quick interview though I think that may be because there is less to talk about with PSV. No ideas about PSV-- I think she might have said in the bathroom that she thought it was bringing air in and sucking out which isn't quite right - but again she was reluctant to just guess.

Joy

Very quick interview as she is busy and not much to say- she didn't know she had the PSV. Only when I pointed it out to her in the utility room did she say - 'oh yes that's the fan' but she didn't seem to know how the system worked. All the windows were closed (except the kitchen) - she opened one vent to show me. Overall she's happy though her bills do seem quite high (£100pcm?). Not sure where she's from but she's not English. Perhaps African though this is a guess. I couldn't go in all the rooms but there was a big fan on the 1st floor landing and on the top floor I spotted a smaller desk fan in the front bedroom. Interesting that people do seem to use these fans quite a lot - but at the same time are quite concerned about saving money on the bills. No interest in environmental stuff - much more interested in saving money. The vents looked quite dirty / dusty (I wonder if this will show up in the photos). They read the instruction manual and she said the kids did too and that based on this she understood how things worked. But she said they closed the vents in the winter. Hers is one of the bigger homes I think - I wonder of this was the one who left the immersion heater on? Massive TV (probably double Ed's one almost). It felt really warm and dark in the house. Upstairs a bit damp and stuffy. No fans running though. Net curtains on all the windows but she seemed to suggest these were decoration rather than functional. She works night so probably at home during the day when kids are at school. Not English but speaking English to each other. Energy monitor in prominent place in the hallway by front door.

Christopher

Good interview. Sustainable attitude. Informed architect who is practicing what he preaches. After recording stopped he spoke about how technology is less than half of the answer and that people are important. There was no community engagement driving the design process. He said something like 'the residents were just taken off the housing register'. Interesting how they used MVHR in subsequent projects. Interesting how he described MEV as 'fit and forget' but then later talks about how you need to use the 'night vent mode' to stop overheating (so he IS aware of different seasonal operation). The summer mode seems to rely on windows being open at night (tilt and turn) and the rooflight and all windows closed during the day. But then in my interview with the resident [Sabeen] all the windows were open when I went round (though this was more of a between seasons as it was a mild spring day). When I asked him about the idea to have a communal garden he said that his idea was to have small private gardens and then a communal garden, but apparently the planners didn't like it. He then went on to describe the [name of local authority at Case A] planners as a 'nightmare' or similar which is interesting as there is some ugly stuff being built in [name of area] (near station!)

He did seem to have quite an idealised view of the residents in terms of the ventilation, but less so in terms of the energy consumption. He spoke about how some families used way more electricity than others because some cared a lot and others didn't care (I like the way he mentions tropical fish tanks). I need to speak to the RSL and the M&E people as well as more residents (do any of the residents know about this night vent mode and are they doing it?).

Richard

n/a

Eddie

n/a

Yvonne

n/a

Mark

He didn't know which ventilation system was in place as this was chosen post planning (or at least if it was already decided this was not a planning consideration and he was not aware of it. House layouts are predetermined by [developer] while the flats were more bespoke. Sustainability doesn't seem to be a big driver at the start of the scheme but at some point must have been introduced (look over notes with [RSL] people before interviewing [developer]). Interesting that sustainable design doesn't seem to be of much interest to him, but the practice he works for have quite a vocal (apparently) sustainability agenda as demonstrated by the photos I took in the loo and lobby which talked about the special design features of the architect's studio.

Dominic

Very technical guy. Not that interested in sustainable design, especially in comparison to the other two cases. His definition of sustainability is more to do with ticking code boxes and other such requirements. He understands the systems well technically but doesn't seem to know that much about POE or handover (if anything). Completely different from the other two architects I'd met so far.

Stuart

n/a

Janet

n/a

Brian

n/a

Helen

Fascinating interview. Story about how [rival housebuilder] want to do MVHR in a 5 ACH scheme because they get points for doing MVHR and points for building to 5 ACH or lower (I guess this is probably a BREEAM thing) despite the fact that she advised then that there was no point using MVHR unless the dwellings were more airtight than 5. Really interesting conversation about the wider aspects of ventilation and sustainability although in terms of actual details of the scheme she was not able to go into that much detail because she was not the project architect. Really interesting bit when she got quite emotional about the issue of POE and who is going to do it and pay for it. The fact that architects can't get money for POE is fascinating as they do appear (so far) to be the person in the team who is most passionate and knowledgeable about sustainability and therefore perhaps more able to do a good job. Also another example of an architect living with the same system or specified in the project that we are discussing - importance of personal experience on design practice? Although the PSV in their house was different because they don't have trickle vents. The reason for this is that her partner said that in Germany you don't need trickle vents and that they trust people to control the ventilation themselves, something which is not possible with our current building regs. Apparently he managed to sweet talk the building control man because he was out of his depth anyway and didn't understand any of the things that they were doing. However this is less likely to be the case now. Another important issue arising from the interview was the idea that the resident experiencing the dust may have been imagining or exaggerating it - something that I had not really picked up on but which could have a big impact on my work. I wonder if I could speak to her husband to get a different perspective from the same household. Even so, it doesn't really matter - the fact is that she is distressed and cannot seem to get help, and also that her home is not as low energy as it might be. Why did she get fixated on dust? What has happened? (and why did [RSL] send me to her house!?). The role of the RSL was implicit in our conversation I sensed although I'm not sure how much was actually said. I got the impression that she was being a little cautious about saying anything negative about [RSL] (which is of course reasonable given their professional relationship). However, there does seem to be a missing link between the residents and the RSL - there is no-one they have regular contact with and no way of getting help, or communicating problems to the higher levels of management, who presumable are the ones who can actually change things. Money is always tight in social housing so naturally this may be an issue and it sounds from what she said and what [supervisor’s name] said that there has been some kind of financial shake up at [RSL]. However, the fact still stands that they do seem to have quite a distant relationship with their residents and I wonder if this will be less so at [RSL, Case A] as they are a much smaller RSL.

Martin

After we spoke he agreed to find out who from his side was on site. He said that chances are they still work for him. Interesting that they seem to retain their workforce. It was also interesting that he didn't want to / or couldn't explain how the system worked to me. Part of the reason might be because we were quite rushed and he said at the start that he only had half an hour so I was quite direct with my questions and didn't get as deep as perhaps I would have liked to. Interesting that he didn't think it was possible that the pipes all went in vertical because joists and beams would have got in the way (this was done before the BPEC course so I wasn't aware of the 45 degree rule but I wonder how many bends there were?). What really stood out was that he was saying how without enough ventilation you would die and gave the anecdote of a recent site meeting. Actually I think it is virtually impossible to build a building airtight enough for people to run out of oxygen (check with Tadj). He talked about condensation and humidity and seemed knowledgeable about airtightness. But he didn't talk about mould and didn't seem to be aware of the BPEC course and accreditation. He raised the issue of BIM and how that would help with things. He was the first person who I have spoken to who raised this, and interesting that in relation to routing the ductwork correctly - this is a good point. Ventilation system decision based on cost - MVHR easier to specify than PSV say?

Michael and Douglas (interviewed together)

No support of any kind provided for residents with problems. They were quite surprised by the dust story (it sounds like she's the house that is using all way more energy than the other dwellings - I think they said 7 times more) (see the MSc dissertation on this). Also interesting that they hadn't heard about the problem, which means that the report I had written hadn't got through to them. It's not really clear who reports to whom. They talk about their residents as ‘Clients’ and themselves as 'landlords' which gives the impression to me of being quite detached and impersonal, although one of them, at least, had met some residents. Interesting that the main feedback they had was from the UCL study, shows value of this kind of work but also that they are not doing POE. However, at the start of the interview they spoke about how they had just started a sustainability team internally and I know from [supervisor] that they are recruiting for sustainability consultants so perhaps they are doing more now than they were then. Overall they seemed more concerned with money and providing affordable heating, rather than other aspects of sustainability. However, because there were two people in the interview we ran out of time and I wasn't able to ask the questions about sustainability at the end of my schedule so there may have been stuff that wasn't discussed. Overall, I got the feeling that sustainability (I think they used the term eco homes) was about heating bills rather than things like social sustainability and community. They procure via D&B contracts so not a lot of involvement during construction and they seem to outsource a lot of the work to external consultants. It's nice that they have tried various ideas about improving the handover process - the DVD, using a graphic designer etc although financial issues seem to impede the actual success and workability of these projects. Must follow them up to get copies of the design guide etc and to speak to the M&E person. They spoke quite a lot about learning and the technical officer was knowledgeable about ventilation, although he didn't seem to have been that involved at Case C.

Appendix B.2: Analysis memos

These memos were written during coding and analysis of interview transcripts:

Ali

On the second analysis (as this was one of the pilot interviews) it's interesting being a bit more specific in term of what I'm looking for. He makes some interesting comments about adaptation and the way the architect's ideas conflict with the way people actually live which relates strongly to Schatzki's ideas of constraint and enablement. Overall in all this analysis it is coming out that opening some windows (and at certain times of day) seems to be enabled while others are constrained (rooflight) which might be affecting energy use. It's quite interesting to remember the task I asked the first group or residents to do with the word cards. I didn't do this in the second round of interviews because it was taking up too much time but in hindsight I wish I'd kept the cards with me and used them to prompt the less talkative residents (i.e. the youngest resident at the MVHR site).

Sabeen

16/01/14: Possible themes to explore:

- Previous experience of a damp and overcrowded home
- Happy to be presented with new blank canvas to furnish as they pleased
- Would prefer a separate kitchen because cooking smells get embedded in the sofas and so on in an open plan arrangement.

Regular routine of opening windows in the morning and leaving them open as much as possible during the day unless heating is on. Then closes at night to prevent insects coming in- this is the reverse of the night ventilation that the architect envisaged and which is recommended to prevent overheating during hot weather. The insects seem to play a critical role here and should be explored father I think - example of non-human entities affecting ventilation practices

16/01/14: I've set up some nodes to code against based on the exploratory fieldwork (eceee paper) and also some ideas coming out of reading Schatzki. This relates to the 'focus coding' stage of grounded theory discussed in (Sbaraini et al., 2011).

Key points:

- Uses boost switch when cooking
- Opens windows as much as possible during the day

- Close windows at night to prevent insects coming in as they are afraid of bugs and spiders
- House prone to stuffiness and overheating
- Use electric fans (floor and desk) to combat overheating during summer
- Use skylight during summer days
- Tiny bit of mould on window frames in bedroom
- One off events seem to be triggers for new practices

This is the resident with the faulty fire alarm which beeps every minute- Interesting that this hasn't prompted more action and the fact that she is putting up with it when to me it seemed really annoying

Fara

17/01/14: When they moved here they liked the fact it was a brand new house. A key constraint in this home is the language barrier as the parents can't speak much English (Dad some, Mother none whatsoever). Also the size of the family (8 children aged 16 & under, 2 parents and a grandfather) means they have very little money (Dad's the only one working). There is also a child with a disability (I think the RSL mentioned Autism in the interview) who makes a mess and needs to be protected. They've had quite a bit of interaction with [name of RSL] (via the daughter) and are using the booster as intended and maintaining the extract vents. However, one of the inlets is damaged. I liked the story about the stool being lent to the neighbours so they can reach the fire alarm to change the battery! There is overheating during the summer. Windows are open but they are still using fans too. The problems with damp in a previous home may have triggered their desire to bring lots of 'good' air in and open windows regularly. However, they are still doing daily airing during winter which theoretically shouldn't be necessary although it is debatable whether the MEV system is designed to ventilate a 4 bed house occupied by 11 people. Generally they are happy with their house and there don't seem to be any major issues. Their drivers are most certainly saving money rather than the environment.

Karen

17/01/14: Couple with 3 teenage children. They have a dog who the mother-in-law comes to look after daily, and she is involved in opening and closing windows too. They find the loft space unpractical and feel unsafe accessing it. They changed the floor because they didn't like it - more agency than other families to change their surroundings. They also took out the separate recycling bins and put in a dishwasher. It seems like one off events are quite important in the development of new practices - i.e. Janet’s visit and getting the children to turn off appliances One of the inlet covers has broken like in Fara’s house. The wardrobe is obstructing the vent in their bedroom - the architect's design doesn't really fit in with their decorating/homemaking practices.

20/01/13: Serious overheating. Dog affects domestic practices. Changed the flooring and generally seem to have a bit more money than others on the development. Heavy appliance users. Trying to cut down on energy use mainly for financial reasons. The furniture in master bedroom is obstructing the wall inlet.

Pamela

20/01/14: Single Mum living with 2 adult children and one teenager with learning disabilities.

21/01/14: Some dissatisfaction with the house as there have been some maintenance issues and also it's too hot in the summer and too cold in the winter. This property is more expensive than her previous home to run (though I wonder if rising utility prices have anything to do with it too?). Also, it's probably a bigger house than her previous one. She seems to have had quite high expectations about the new house, many of which haven't been met which is leading to some disappointment - such as the high bills and the fact the air isn't any different to that in her friend’s council house. Despite the fact that the family's health is much better (less asthma and winter colds) she doesn't seem to put much value on the quality of the air in the property. Very small amount of condensation (in kitchen and LR) and no mould. According to her, this is one of the largest properties on the estate. It doesn't sound like the MEV is working very well which might be down to the fact that it hasn't been maintained properly. She has no idea about the AHU nor about filters. They use an A/C unit and fans in every room - as well as opening all the doors, windows and skylight in the summer to stay cool - overheating is a problem in all these houses by the sounds of it and is interfering with the MEV as windows are being used instead. The fact that there is little mould or evidence of damp problems is reassuring - it seems likely that the correct air change rates are being provided - the issue is that windows seem to be being used quite a lot and energy performance may be compromised.

Betty

18/02/14: Remember there are lots of notes about this in the document I wrote in Year 1. Could be worth bringing into NVivo and recoding? She is quite in tune with nature and is the only one at this site (I think) who mentions the direction we are facing and the movement of the sun. She clearly spends quite a lot of time at home alone. She wasn't opening any windows at first as she couldn't take them off the latch and she didn’t think they were useful only open a little bit. When one of the POE consultants showed her how to open them wider she may have changed her behaviour (checked photos from second year visit - can't tell if hers open). Interestingly, having spoken to other residents at this block I now feel like her understanding of the MVHR isn't actually that bad! She knows

> *'it’s supposed to take out smells and it brings in fresh air, it re-diverts the air [….] Recirculated the air-- because when she’s cooking downstairs I get her meal coming through there.’*

So the misunderstanding is the recirculation but actually she was one of the few I think who knows it's bringing in fresh air. Maybe need to relook at the matrix. She doesn't do much cooking so probably not really testing the MVHR to its max. She wasn't opening the windows but that was more to do with the fact that she couldn't get them off the latch, she only has one key and believes she has to keep them all locked and also she can't reach the high level one in the kitchen. Also, one of the windows (at least) was too stiff for her to open (she is elderly). All in all a lot of constraints that may be blocking her use of the windows. This is good in terms of her not opening them during winter but means that any data measured at this flat might assume a deliberate 'correct' behaviour whereas actually it's not the case. In fact I don't think many of the behaviours/practices I have encountered are deliberately concerned with saving energy. Most of the time it is incidental.

19/02/14; Also, she'd only lived there 6 months so hasn't experienced a summer there yet. Therefore it's hard to say what her 'complete' practice will be.

Paul

12/02/14: He is pretty adamant that he ventilates by opening the windows and doors, both of which were open at the time of the interview despite the average temperature that day being 4 degrees C. He says he opens windows all the time especially when he's cooking and says that's because they aren't allowed to have a cooker hood until they've lived there for 2 years. Sounds like ventilation is working okay as he hasn't noticed any damp or condensation and bathroom moisture seems to be clearing okay (though it is only one person so it should be relatively easy to deal with). He didn't really know he had a 'ventilation system' although he's using the booster and aware of the inlet and outlets being in each room. However, he made the (sensible) assumption that they were all extracting air and didn't realise they were supplying it too. I think he's got confused between the MVHR system and the monitoring carried out by [name of consultancy]. So he says he was told not to touch the MVHR vents as ‘It’s part of an experiment'. He has the windows open ALL the time as he smokes heavily and has a condition where he sweats a lot from his head (sounds like craniofacial hyperhidrosis, or excessive sweating of the face, head, or scalp). He doesn't think [name of developer] are very helpful when it comes to fixing issues whereas with [name of RSL] the service is more variable.

13/02/14: He gets quite angry about energy saving and doesn't think it's worth bothering as power companies are to blame and he seems to feel powerless to make a significant difference. He also describes himself as lazy which suggests he has quite a passive personality.

Dan

13/02/14. Previous home was his car. He didn't have a look round before he moved in as the homes hadn't been built yet. He has the best understanding of his ventilation system of any of the residents I've spoken to so far, though he mistakenly believes that warm air is being recirculated (i.e. that air is mixing in the AHU). He's also scared of spiders so won't leave the windows open at night. Good in terms of MVHR performance but could be a problem in the summer. Says the booster is manual so he has to switch it on and off which I'm surprised by - I would think it's on a timer - need to check the spec. His previous experience of mould and lack of ventilation seems to have contributed to his appreciation of the system he now has. Things seem to be working well and there are no issues with mould or condensation. He describes how he sets the heating manually by turning the thermostat up and down (does this mean that potentially the heating could be running 24/7 unless he is turning it down low enough to definitely not come on? Maybe the homes are well enough insulated to prevent this being an issue? It doesn't help that he is waiting for [RSL] to come and fix the screen on his thermostat which is broken and so he can't set the timer). He says that he uses the booster in the kitchen after mentioning that there is no window in the kitchen. I think this is important and might explain why people in the MEV case aren't using the booster so much - they can just open the window instead - so window is the 'first choice' ventilation method and if that's not available they look for alternatives.

Anthony

1702/14: He knows about the MVHR and is able to talk about it and is generally quite articulate. However, he isn't aware of how the MVHR works. He thinks the AHU is removing moisture and then pushing the air back in and is not sure if it is being warmed or not. It's kind of right but this belief suggests that the air is being recirculated which is probably why he's still opening the windows. Very interesting conversation about how he prefers the air coming in through the window than the ventilation system and that he leaves the windows open at night otherwise its gets stuffy. There's a great quote about how he doesn't think the MVHR is enough to dispense with the need for window opening (L.138). He has developed some health complaints since moving to a home with MVHR (first the one before this and now this home - cough) and he thinks it could be responsible. (quite possible but could also be the fact that both were new homes and there may still be a high concentration of VOCs). He's looked in the instruction manual as he was trying to figure out how to increase the temperature of water in the bath as it's not warm enough to have a bath - i.e. 'troubleshooting'. This constraint (lukewarm water) prompted him to look at the instructions. No maintenance done yet but he's only been there 6 months. Relies on sounds to tell if the MVHR is working or not. He and his wife have slightly different thermal comfort requirements which might explain why he likes the window open - I think it is to do with thermal comfort rather than ventilation per se. He likes a cooler room and doesn't think the MVHR is able to provide that (of course not - that is not his job - should probably turn the heating down. he says they have it between 21°C and 23°C so quite warm) He's the first (see also Luke) person mentioning using blinds to block out the sun as a way of coping with overheating. He also thought the inlets and outlets were dual purpose. They put down a carpet which might have interfered with the flow of air except that they leave the doors open so it's okay. Least concerned about the environment out of anyone I met *'I'm with Jeremy Clarkson'*. He makes an interesting comment towards the end that he is impressed that they use modern technology in social housing which he expected they'd only do in expensive homes (it's his first experience of social housing).

Steve

17.02.14: Carpet is another potential physical constraint that interferes with ventilation. Several people have mentioned putting down carpet when they moved in to a new home. He doesn't use the booster as it's too noisy and you can hear it in his bedroom. When he's had a shower or done some steamy cooking he opens the doors and windows to ventilate. He relies on his stepdaughter and his brother for help with his bills and household affairs as he can't read very well. I love the way he is inspired by my visit to test his booster after I leave. I wonder if he did it? This shows what a strong effect interaction with experts can have on a resident's practices.

Luke

18/02/14: Describes himself as lazy (another one!). Doesn't think the booster is doing much so doesn't use it often - sometimes when cooking. Very laid back personality, not bothered by much. He uses the curtains to block out the sun when it gets very hot in summer and opens the windows a lot. He is another one who uses the curtains to block out sun - maybe this is more important in a single aspect flat, especially one that faces west/south (check orientation). He also leaves the boiler switched off at all times to save money and just turns it on when he wants hot water i.e. shower. He's using an electric fan in the summer, despite being very laid back about temperature and the fact that he actually had to leave the flat on occasion because it was so hot is a sign that the overheating might have been quite severe (I might have some data or maybe [name] has some??). He has clearly picked up something from being involved in the in depth POE though it is hard to say what.

Carla

04/02/14: She is not happy with the house for 3 main reasons:

- Poor quality materials and finishes
- Tendency to gather dust
- Expensive utility bills (though house is bigger -4 bed, not 2)

They keep windows closed to try and stop the dust coming in though it doesn't seem to be helping much. Parts of the house get very hot (i.e. top) while others require heating so they leave windows open - presumably this is wasting lots of heat. The issue with this house is not over or under heating as such, rather the variability in temperatures across the space (or perhaps between the thermal comfort requirements of the members of the household). She sometimes puts the thermostat up to 30 to stay warm! They close trickle vents during winter because otherwise it's cold. They have the heating on 24/7 which is not good. There's also not enough hot water to have a bath. Dust and cold water are possible constraints? Also worries about rain coming through rooflight. She moved the wardrobe in front of one of the windows in her bedroom to reduce the draughts, which also blocks out some of the light. Another possible constraint is the space taken up by recycling - I think Betty had a similar issue. She talks in the present tense even when she is referring to past events - English probably not first language.

She has a cooker hood which I don't think the other participants at this site did - I wonder if she put it in herself? Interesting that she is still having to open the windows too.

07/02/14: This is an end of terrace house to the east of the site (NW elevation is connected to neighbouring property) which may explain some of the thermal variation across the spaces.

Sarah

31/01/14

She keeps front door and back door open a lot - obviously feels secure in the area. Keeps door open even in winter - can't be great for energy use. She says the sun shines on it all year. Cooking smells travel upstairs. This is the only scheme which has solar panels (solar thermal I think). Her house has 2 toilets and 1 bathroom with toilet. She gets condensation on the bathroom mirror. They are getting some mould round the bathroom tiles. She spoke to her neighbour about black mould on the bath and started using bleach after that. The house is cool in the summer - as long as she closes the curtains. She also leaves the window open overnight on the latch. She's quite energy aware, using an aerator on taps and an Owl monitor in the kitchen. Also uses water butt to water garden. She is very careful about saving money and pays her bills on a prepay card. Worries about the cost of water. Lots of windows seem to be open most of the time! Pays about £30pcm for gas (heating and water - cooker is electric) - check this - line 500. Seems reasonable for a big house - esp. given she's on prepay. Windows open all the time might be affecting the heating bills. The thermostat was set to 24 degrees! She doesn't know what it's on because of her eyesight! I think this could be an interesting thing to write about.

Joy

03/02/14

Experience of serious mould and condensation in previous home. She knows that the trickle vents have to be open all the time and also opens windows to make sure the home is well ventilated. She is aware of the 'passive' nature of her ventilation and the location of extract vents. She also knows about the trickle vents. She volunteered information about both without much prompting - seems to be a bit more aware of ventilation, possibly due to her previous experience. They don't have a cooker extract and are thinking of getting one. Downstairs bathroom has no window, just the extract vent, which seems to be working fine. She's happy with the quality of the air in the home describing it as 'comfortable' on several occasions. Also happy with temperatures - it's warm in winter and cool in the summer. The safety latch seems to be popular - so she can open the window when she goes out. Similar story to Ali's - the RSL forgot to give them the pole to open the bathroom rooflight - and they also don't do it so often because of bees and spiders and rain. They have the heating on a timer, which her husband programmes to come on early mornings and in the afternoon when they come home. They interact with the timer quite a lot 'move the things' so that the heating is only on when they are in the house. The thermostat is in the hallway downstairs, while the timer and boiler controls are upstairs in the boiler cupboard. Occasionally, such as when they are going out they use the thermostat to 'programme' the heating (it sounds like they are turning it down to stop the heating coming on when they are out – 258). Husband in charge of bills and also the one to programme the timer on the heating. She cares a lot about environmental issues and is keen on recycling and reusing water bottles. This makes her feel 'nice'. They use an electric radiator in the garden sometimes on summer evenings! There's a second electric heater in a cupboard downstairs too.

Christopher

23/01/11: Ideas to look out for while coding:

- Ideas about how the architect imagines the resident might be using the house and engaging with the ventilation technology.
- Also architect presumably has his own set of constraints within which he is operating (regulation, the client, the contractor... maybe others?) and it would be interesting to consider how these factors may be expressed in the built form of the building and actually constrain or enable the actions of the residents within.

Initial thoughts on reading (pre coding):

Very high aspirations for the project but also quite early in terms of eco social housing (complete 2008). Interesting that robust and economical were priorities - has this actually been realised? Overall a positive relationship between architect and client as they have gone on to build several more schemes afterwards. Also interesting that they have gone on to use MVHR in subsequent projects. He has actually had some engagement with the householders post occupancy (as did PSV but not MVHR at all). His opinion of the houses is that they are very standard and simple to use, whereas actually for the residents they are quite unusual compared to their previous homes and not necessarily that simple to use. MEV sounds much simpler to fit from the contractor/builder (and detailer)'s point for view, but actually from my interviews with the residents it isn't necessarily that simple to use. He says he probably wouldn't use MEV again as the energy benefits of MVHR are worth it. He has a very good understanding of energy and ventilation issues. Conventional full detail contract

Issues mentioned or revealed during interview (possible codes):

- Quality of workmanship
- Needs to be robust and easy to use
- Cost
- Client relationship
- Energy performance
- Performance targets
- Sustainable materials
- Overheating
- Refinements made in subsequent projects - DA was a prototype

- Understanding of ventilation technology (his own, his wife's and the tenants')
- Hasn't seen the domestic ventilation compliance guide
- Ideas about why people ventilation / purpose of ventilation

Architect's practices:

- detailing
- supervising construction
- specifying finishes, materials and systems
- working with consultants
- communicating with their client
- hearing feedback from building users
- Providing information for tenants
- Commissioning of ventilation
- Monitoring energy use after occupation

A really critical argument I think is the one between his idea of how night ventilation is a simple concept that people are able to do, probably based on the fact that he has been doing it in his house for many years, and the experiences of the residents who I spoke to who are less able to do as he imagines because of various constraints. One of those is the lack of knowledge (so not a physical or spatial entity) but also there are some material constraints too - fear of bugs, fear of water coming in exacerbated by the fact that the rooflight is hard to reach and fears about security.

Richard
20/01/14: He's an M&E consultant and an expert on ventilation. At [Case A] he was actually only involved in POE work - looking at the energy performance of the occupied scheme. Doesn't seem to think that MEV needs much maintenance which is interesting given that he is an expert on ventilation. Says he was initially unsure about summer bypass modes (control issues) but as the technology has improved he sees it as useful.

Eddie
24/01/14: Green Doctor. 500 homes. Likes getting inside people's homes. Could RSL constrain or enable behaviours? How? I suppose with the Green Doctor they are trying to enable but if the spatial arrangement is constraining then presumably there's a limit on how much information and training can achieve.

RSL Practices

- Giving advice
- Visiting tenants' homes
- Managing the start of the Green Doctor programme
- Piloting Green Doctor at [Case A]
- Working with architects

- Building new homes
- Acquiring new homes from other RSL
- Belonging to AECB and GHA as member and attending their events.
- Learning about new technologies

He describes homes without mechanical ventilation as 'normal' which is quite telling.

Is an 'automatic' system constraining or enabling?

27/01/14: He made a few references to some of the residents, including some of the ones I have met.

Yvonne

28/01/14: Doing a job share with Eddie. He's Manager and she's officer. She sees herself as less technical than Eddie. Neither of them were actually around when Case A was being designed and built – [name and name] would be the people to speak to about that. Remember that this interview was conducted after I presented my first year's findings at the meeting so she knows what my work is about and her answers may be influenced by the issues I raised in the talk. Really important section about the role of the social landlord with regards to enabling tenants to use the home in the way it is supposed to be used to 'run the house properly'.

Mark

24/02/14: Something that keeps coming up among the professional participants is that of 'fabric first' approach to construction. This means that the buildings are well insulated and airtight so that whole house ventilation is required. Renewables are always discussed as a bolt-on in a kind of pejorative manner. I've always been an advocate of fabric first but it does seem to be a driver towards the MVHR route. The planning architect hasn’t been to site for several years (at time of interview) so hadn't really had a chance to learn from his project. He emphasises the aim of the scheme to regenerate the area and seems to measure the success of the project in that it is better than what was there before, rather than it being a particularly successful design in itself. He didn't know what the ventilation strategy is and thought the homes were naturally ventilated. He seemed quite surprised when I told him it was actually MVHR. I think it's amazing really that the choice of ventilation strategy is not considered until after planning. So different from the other two projects where it was much more integrated and decided from the outset (by the architects). He made some great comments about how ventilation was not really something that would be considered at the planning stage (!). Also, he did not know what [consultant]'s involvement with the project was and suggested that the RSL were the ones driving their application for the funding. So at the planning stage the planners require detailed information about how the bin stores work but are not required to state the ventilation/environmental strategy!? He has quite a good technical understanding of how MVHR works although he was unsure whether in a flat there was one centralised AHU or individual units as he's never been involved in one before.

25/02/14

The original scheme was for CSH3 properties but the [name of organisation] sought (and found) additional funding to upgrade some (or all? Surely if there is MVHR across the site?) of the properties to CSH4. I guess this would have been the point at which MVHR has introduced which was after this architect was no longer involved. I wonder if that had an influence of why MVHR was chosen - if it had been considered earlier on they could have designed the homes differently? Was it the cheapest way of meeting CSH4 at that point... or is that always the case? This also means that the MVHR was retrofitted (in design terms) which may have led to issues or at least complications for all involved. Especially in homes for private sale where space standards are even lower than for social rental this could have serious implications for things like storage space. He describes himself as 'slightly dubious' about Passivhaus because you can't open windows which is slightly missing the point.

Dominic

25/02/14: It sounds as though the contractor was responsible for choosing MVHR in this project. (unlike in the other two where it was the architect). It certainly wasn't the planning architect as he had no idea and it sounds from the construction architect that the decision was made before he got involved. So when did it happen?! There is some confusion about when the decision to use MVHR was made. The construction architect suggests that it was part of the 'initial energy strategy' but I certainly didn't get that impression from the planning architect. Interesting 'constraint' that comes up for the first time here - developers not wanting to put the inlet vents above the TV (which is usually at the opposite side of the room from the door and therefore directly below where the best theoretical position for the inlet is). This is a sales/marketing issue - they'd rather put them above the door so that people don't notice them when they walk into the room. Says that contracts prefer system 1 and try to avoid MVHR as it's harder to build. This is an interesting interview as he talks a lot about some of the spatial components of MVHR, in particular things like ducting and position of extract and inlet vents and also the position of the AHU with respect to soil stack pipes. Sounds like the only reason he knows what and O&M manual looks like is because his sister moved into a new flat! He doesn't think using MVHR requires any difference in window use. Nor that it is sufficient to get rid of pollutants such as paint vapour. This does seem to be missing the point a little to me. He's quite happy with the concept of MVHR and believes it is becoming more and more common and will soon become the norm (2016) He thinks it will become acceptable to residents once it's silent so they barely know it's there. He's very technical and not in the slightest bit creative by the sound of it. He talks a lot about checklists and regulations - clearly compliance is a major part of his job. When asked about sustainability he went into a long discussion of CSH and how they score points with bin stores and level thresholds!! It sounds like complying with Code is a bureaucratic nightmare. Interesting section about how he had cavity wall insulation and a new boiler installed at home and since then has had trouble drying clothes as it's too warm inside for the radiators to come on. He says he thinks the SAP allowance for airtightness would have been 6 or 8 (ACH I assume) which is quite high for a dwelling with MVHR. Can I find out what the actual measured airtightness was? I'm sure it was lower. Discussing whether he's ever specified louvres, he talks about how it can be hard because his hands are tied by what's been done at planning so he can't make any decisions by his point. But at planning they hadn't actually chosen the ventilation strategy yet so how did they know whether they were going to need shading or not? I feel like there is a massive disjunction here. At the planning stage they are making decisions based on an 'outline' proposal which is not detailed enough to include M&E and then by the time it gets to the working drawing stage when things are detailed up, it's too late to make some changes.

Stuart

24/02/14: He talks quite a bit about residents doing things that they shouldn't with respect to MVHR, such as switching it off and not changing filters. He also says how they are trying to move away from MVHR in subsequent projects because of some of these issues they've had and use system 3 instead (MEV) although I was surprised that he has been advised that you can use MEV without inlets, relying on leakiness instead! (3-5 ACH). He is quite technical and knowledgeable about MVHR. He made some interesting comments about how he thinks it's best to position ceiling vents as far away as possible from the door to get the maximum circulation of air across the room but that others disagree (L.161). The issue of general needs vs shared ownership is interesting as the former have their maintenance carried out for them and the latter are responsible for it themselves. This could be a discussion point for the whole thesis as all my participants are general needs (except 2 here) and what will happen in private tenancy and ownership situations is another story completely! Such a long running and big project that the contractor who I spoke to hadn't actually been there since the beginning. So the homes I am looking at were pretty much ready to put the roof on when he joined the company. When it comes to choosing the actual system, large contractors get 'group deals' with the big companies (Titon, Greenwood) so they approach then to find the cheapest manufacturer to comply with their chosen Code target. A lot of what he talks about is complying with the many regulations and standards that they have to adhere to at the lowest cost. So for example, they didn't install cooker hoods because it was not necessary to pass building regs. He makes a great comment on how if tenants have read the book they'll be fine! I think if they’ve read the book and understand-- or understood the principle of how it was supposed to work and they’ve managed it as it’s supposed to work I think they would be fine. There is an inherent assumption in the way he speaks that the resident needs to understand and want to engage with the MVHR for the home to function properly and in cases where they don’t want to engage with it then alternative ventilation strategies may be more appropriate.

Janet

20/02/14: This RSL are a big organisation and split across two sites. Much like the PSV one there is a division between the delivery teams and housing management which could be a problem. Interestingly it looks like the 'neighbourhood managers' have been moved around and changed their roles a bit since I did the interview. She mentioned [name], the SO housing officer who I was never able to get hold of. I wonder if the story about how hard it was to get participant feedback from the SO units for the BUS survey (and interviews) is worth mentioning. I suppose there are two reasons for this 1) Janet was so much more engaged than her counterpart in the other block and 2) it was part of their tenancy agreement so they felt under obligation to take part.

Her understanding of MVHR is quite limited:

> *'There's no-- in the communal areas there's no-- the windows don't open. The heat recovery units are in all flats so they-- as far as I understand it-- they-- they take out foul air and redistribute it and then turn it back into nice clean air again. I don't know if that is the correct way of explaining it [laughs]'*

This is not surprising. She's the only RSL I interviewed who has a day-to-day tenant facing role compared to the others who were more senior and involved in sustainability or development (i.e. more technical roles. She thinks the reason they went for MVHR is to score 'eco' 'points'. Handover process (to tenants) is quite involved. There is a lot of information provided, mostly about who to contact in emergencies, rules (no storage in communal areas etc), and things that are regulated (gas safe boilers) and Secure by Design keys. Energy saving, and staying comfortable in the home didn't really get a mention. It's very 'tickbox' - she mentioned the checklist several times. They are given a large manual but it's not bespoke- rather a generic one with all the possible information in it. At the time of the interview, there was no provision or budget to maintain MVHR and change filters. They had begun to get reports of mould and damp at properties that had been completed earlier and so were investigating how to implement this. They are also becoming more interested in sustainability and are implementing green doctor schemes. The RSL spoke a bit naively about eco-villages and little wind turbines but she was also quite genuinely concerned about environmental issues and in favour of green building. Because of the monitoring, housing managers were told not to tell the tenants anything about the homes saving them money on bills. Perhaps this was to not interfere with the monitoring? Or just a way of managing expectations? Either way, it sounds like vital information about the purpose of MVHR didn't get through because of this.

Brian

Interesting that he knew more about the MVHR filter cleaning and maintenance contract that they'd just put in place than Janet. After all she is the one 'on the ground' and presumably organising this kind of thing and checking that it had been done properly. He's a technical person and understands how MVHR works fully. However, he is mistaken (I think) in believing that some of the residents would understand it as well as he does as no one I spoke to did. He believes that people are leaving their windows open (quite rightly) and that others are not (yes, but one because she didn't know how and the other had a cold). He suggests that an extract only system might be more sensible with windows acting as inlets (obviously this would only be acceptable to building regs as a system 1 with trickle vents) which is what I think they are moving to in subsequent phases of the project. We spoke a bit about the manual and how it can get lost between tenants and how generally people don't look at it unless they have an issue. I think the handover/manual could be a focus for this project as there's quite a lot about it.

Helen

05/02/14: By the sounds of this interview, PSV is very sensitive to installation error - i.e. it's very important to design it in early and that all the ductwork is fully vertical. That's why something like this simply wouldn't have been possible with Case B - which went through planning without a ventilation strategy being chosen... So for PSV to happen it needs to be deliberately planned at the outset of the project. Also doesn't really work with D&B contracts as on site supervision required (at least not unless the contractor knows that they are doing). She believes that it's easier to regulate temperatures in homes with MVHR than PSV which leads to less window opening during winter. I'm not sure if this is right given my experiences at Case B but it's an interesting example of how she makes decisions based on experiences at previous project (i.e. not a statistically significant sample, but just the information she has access to at the forefront of her mind). Funny that she later describes PSV as 'pretty robust' given that it has to be installed so carefully? She is pleased with the scheme and particularly highlighted the important role of the whole team working together as a driver for a successful outcome - and was very positive about the contractor (unlike the MEV architect who had some problems with quality of workmanship and also the contractor has since gone out of business). There’s an interesting bit towards the end of the interview where she talks about how even within the constraints of social housing there are things you can do to make a home more liveable-in, which relates nicely to ideas of constraint and enablement and the agency of the architect within the design team and in relation to the end use of the building.

Martin

06/02/14: Says that decision to use PSV was made by the architect. PSV has to be considered very early on and only works when the detail design architect is on board from the beginning (i.e. with Case B it would be too late if the detail design team had decided to go for PSV - it needed to be in the spec earlier on. Whereas the mechanical system is perhaps easier to detail retrospectively..?). With PSV you have to think a lot about the ducts and air flows in a way that isn't necessary with the other systems (though with them you need to consider commissioning and maintenance). So PSV involves more detailed work earlier on in design process and MV relies on commissioning and aftercare to work effectively. So essentially if you don't consider ventilation from the outset you will be 'pushed' down the MV route. Is this how it happened at Case B or was MVHR always part of the ambition? Not sure now whether the PSV was commissioned or not - Contractor thinks Passivent did it while Architect wasn't sure if it needed any. Neither would have been very closely involved at that stage so hard to work out what happened - are there any other documents?

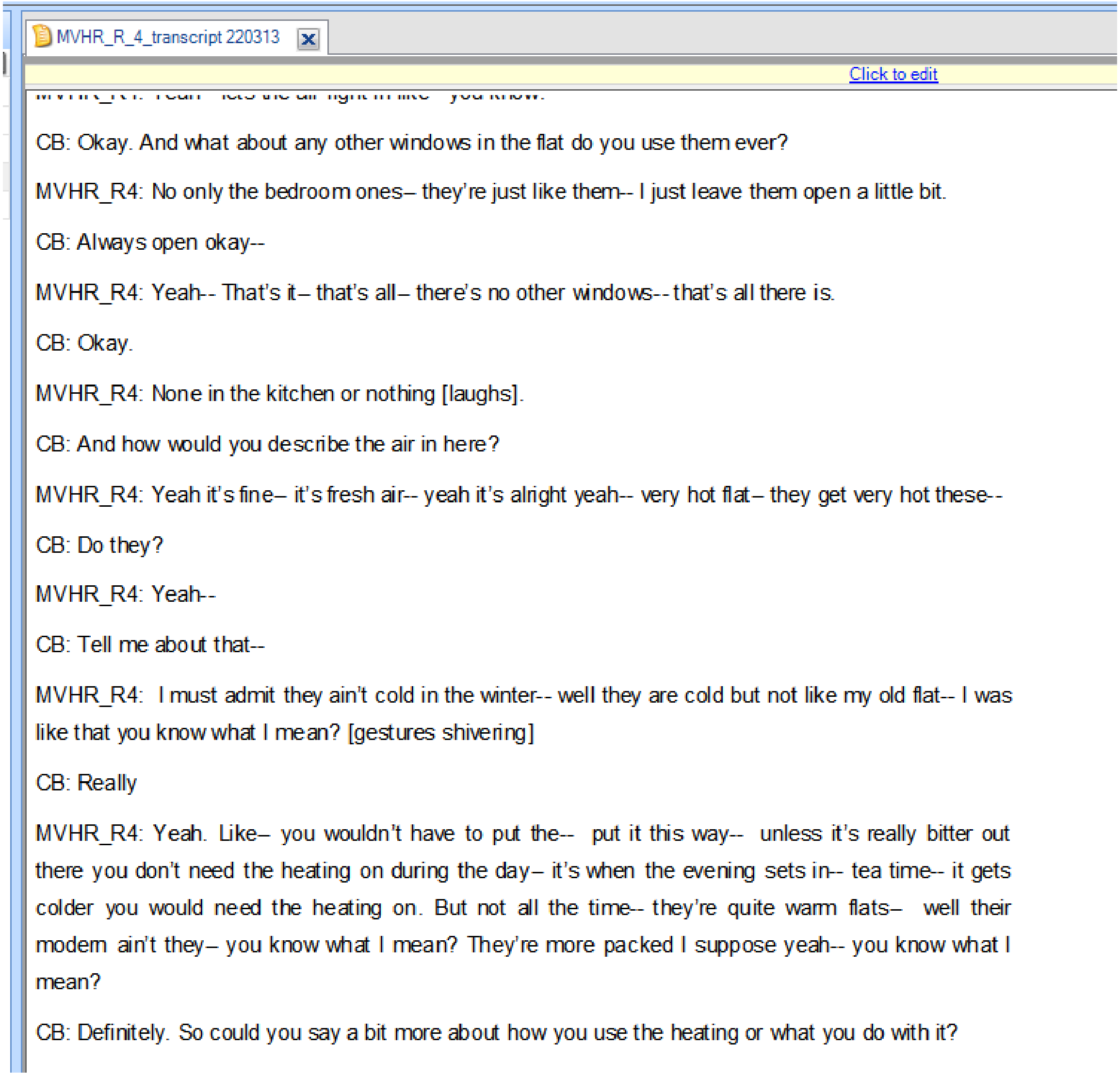
07/02/14: Some good quotes which demonstrate how cost and compliance issues are the main driver for a ventilation strategy, rather than thinking about what would suit the future users of the building best. And unfortunately compliance is based on design values rather than built performance so the possible energy consequences of selecting an inappropriate strategy (if there is such thing - I'm not sure) are not really of interest.

He became interested in sustainable construction because of the relationship with [name of architect's practice]. It fitted in with their ethos of good quality building. One thing that is coming out really strongly from this project is the importance of teamwork in procuring a genuinely sustainable building versus the industry tendency to work in silos - i.e. separate M&E people, energy consultants, contractors not appointed until post-planning, architects not understanding the implications of their designs.

Michael and Douglas

06/02/14: Michael is the Technical Manager - checks drawings and specifications and deals with technical issues as they come up. However, he wasn't really involved in Case C as the team were previously split between north and south London. Douglas was the new Business Manager at the time. The site was owned by [name of local authority] and he was involved in selection of a site and design team and was project manager up until construction began - then passed on to delivery team. They say that they generally let the architect or contractor propose a ventilation strategy and then support their choice. It's generally about meeting the design target at lowest cost. Consequently they are now erring towards MVHR as it lets them achieve a good sustainability rating (e.g. CSH3) without the need for renewables which they regard as technically challenging both in terms of occupant use and installation & maintenance issues (although they did use PSV in at least one subsequent project and are satisfied that it's working there). Another reason for the move towards MVHR seems to be that they aren't building many houses and in general they feel PSV only works on top floor flats and houses. Although in theory they still support it and it's in the design guide (although they now require recirculating cooker hoods too). Reasons for more flats? Probably something to do with developers and money. This project appears quite similar to Case A in that it was an exemplar/prototype so there was quite a lot of learning coming out if it and there has still been which has informed subsequent projects. Both sites did energy monitoring and found a large variation in end use between different households. Both projects were completed a while back now so there has been ample time for the novelty to wear off and for any defects in the design to become apparent. In both cases the developer (RSL) were quite ambitious about the kind of scheme they were developing. Interestingly they all seem to have moved on to MVHR since these early projects, possibly as a result of tightening regulation (Case C) and increased ambition (Case A). Again, there was this conversation of how much information the landlord is expected to provide: 'we're not their mothers'. The POE monitoring in this project was carried out by an MSc student. Without this they wouldn't have received nearly so much feedback so it just shows the importance of the university connection. There is an issue coming out of this about how people behave at home and whether they are to blame for subsequent issues with the ventilation. Clearly I feel that the ventilation system should be able to cope with whatever people choose to do in their homes to feel they are living comfortably. On the other hand there is the fact that they are renting the homes and as a landlord I suppose one should be able to expect reasonable care to be taken in the dwelling otherwise I would charge the tenant for remedial works. So I suppose there is a threshold beyond which some behaviour does become unacceptable (I am not an anarchist!) but at what point I am not sure. The discussion about drying clothes was really interesting. Some landlords won't let people dry clothes on balconies as it looks unsightly but then the new ventilation technologies aren't really designed to cope with the moisture released from drying clothes and so people are being advised to use a tumble dryer which is a) expensive for people in fuel poverty and b) uses more energy and slightly negates the whole point of a low energy house. Their understanding of ventilation is very technical - 'it's condensation control'. Whereas I think the main 'End' that people have in mind when they engage with ventilation technologies and windows in the home is that they want to feel comfortable (thermally and also in their other senses - smells).

Appendix B.3: Example of transcribed data


MVHR_R_4_transcript 220313

Click to edit

CB: Okay. And what about any other windows in the flat do you use them ever?

MVHR_R4: No only the bedroom ones– they're just like them-- I just leave them open a little bit.

CB: Always open okay--

MVHR_R4: Yeah-- That's it– that's all– there's no other windows-- that's all there is.

CB: Okay.

MVHR_R4: None in the kitchen or nothing [laughs].

CB: And how would you describe the air in here?

MVHR_R4: Yeah it's fine– it's fresh air-- yeah it's alright yeah-- very hot flat– they get very hot these--

CB: Do they?

MVHR_R4: Yeah--

CB: Tell me about that--

MVHR_R4: I must admit they ain't cold in the winter-- well they are cold but not like my old flat-- I was like that you know what I mean? [gestures shivering]

CB: Really

MVHR_R4: Yeah. Like– you wouldn't have to put the-- put it this way-- unless it's really bitter out there you don't need the heating on during the day– it's when the evening sets in-- tea time-- it gets colder you would need the heating on. But not all the time-- they're quite warm flats– well their modern ain't they– you know what I mean? They're more packed I suppose yeah-- you know what I mean?

CB: Definitely. So could you say a bit more about how you use the heating or what you do with it?

Figure 65: Extract from interview transcription, (Steve, Case B)

Appendix B.4: Coding categories

Table 23: Test interview codes[185]

Test Interview Codes (listed alphabetically)			
Beliefs about technology	Domestic circumstances	Interview and Interviewee Biases	Relating energy consumption to end use
Bills	Energy Efficiency and Sustainability	M&E Experiences	Small talk
Comparison with previous home	Condensation, dampness and mould	Occupancy	Smoking
Energy and ventilation	Experience of thermal comfort	Opinions of current dwelling	Understanding of Ventilation
Daily routine	External factors	Reasons for ventilating	Understanding of water energy use
Describing previous dwelling	Health and Wellbeing Factors	Reference to infiltration or draughts	Use of space

Table 24: Preliminary interview codes

Preliminary Interview Codes (listed alphabetically)			
Acquisition of knowledge	Dream house	Interviewee terminology	Quality of life
Attempts to help society	Dust	Local area	Reasons for choosing home
Awareness of energy use	Environmental awareness	Loneliness	Recycling
Awareness of design goals	Expectation of home	Maintenance	Reference to developer
Pro-environmental behaviour	Expectations not met	Monitoring equipment	Reflections on interview technique
Belief about what others doing	Expectations of thermal comfort	Motivations for saving energy	Routine and behaviour (change)
Bills	Faith	Mould	Rules
Communication with neighbours	Family conflict over thermal comfort	Noise, sounds	Solar thermal
Communication with RSL	Fresh air	Novelty of gas heating	Space and design
Community centre	Getting help	More important problems	Sustainability and society
Conflict between them and us	Handover	Poor workmanship	Thermal comfort
Confused about heating	Health	Positive features of home	Understanding of ventilation
Connection with nature	Hexagon task	Previous home	Ventilation boost function
Damp	Hot water	Problem with new technology	Ventilation maintenance
Draughts	Internal doors	Problems with boiler	

185 These data were not analysed as part of the data set. Coding was carried out as a practice exercise during the research design stage.

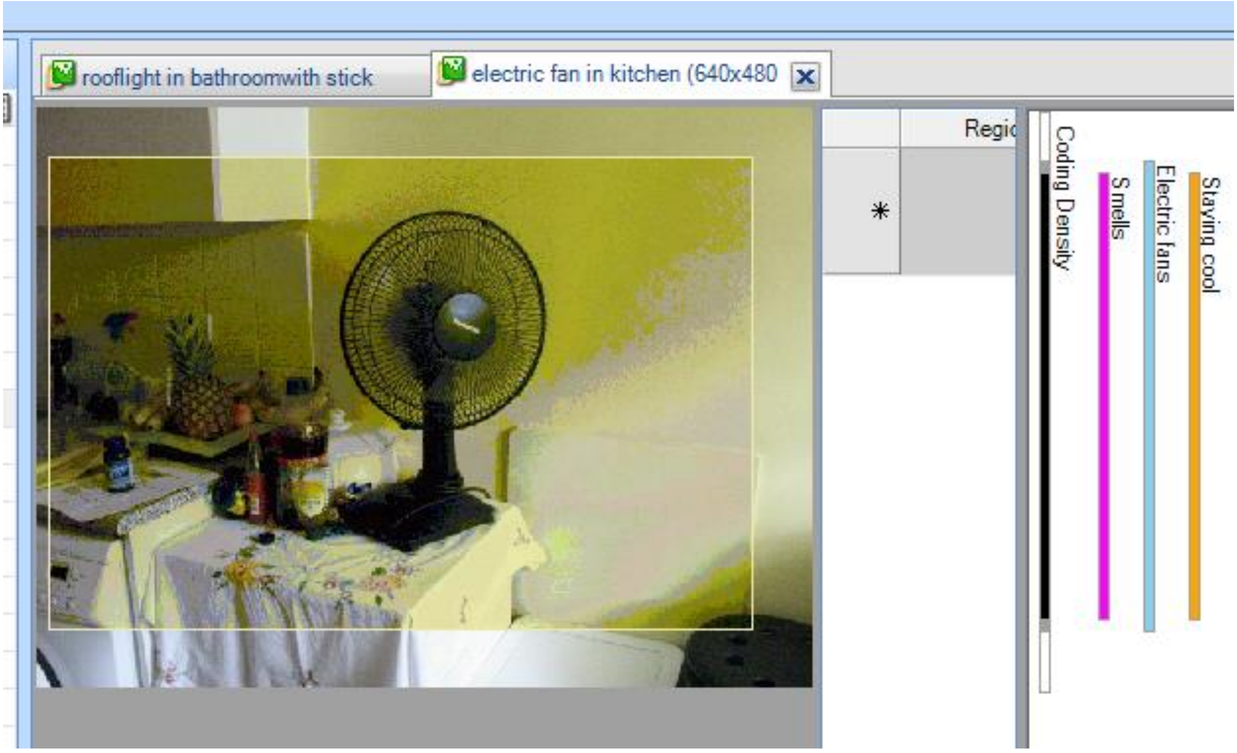


Figure 66: Example of coded photograph

Table 25: Example of coded interview data

Transcript text	Codes
CB: Okay and could you say-- is there anything about the house that you don't like? Anything that bothers you-- Or-- Joy: Well the things I don't like about it is that the windows here-- in the bathrooms there is no window. CB: Right. Joy: It's not-- you know-- it's sealed-- that's one of the things I don't like about the house. But apart of that I actually love everything about it-- yeah. CB: That's great. That's really good. And could you say something about how it compares to your old place as well? Joy: Oh-- My Old place was full-- too chocka-- there was no space in the whole place and over there the house was really cold. We have to spend a lot of money to heat up in the winter but with this one-- you know-- we don't have to like put all the heating on. Sometimes we can just put it for few-- you know-- few hours-- turn it off and the whole place will be okay.	Windows and doors Past experiences Staying warm Routine practices
[Text removed]	
CB: And could you say something about how you would-- for example in the kitchen and the bathrooms-- about how you would get fresh air in there? Joy: Well the bathroom-- as I told you-- there is no window in the bathrooms-- so-- but the kitchen has got a window so like if I'm cooking-- I open the door-- I open the window-- so at least-- you know-- the cooking fume will go out and the fresh air will come in. I do that-- but for the bathroom-- I mean-- When you finish having-- when anyone finish having their bath we just leave the door open.	Windows and curtains Doors Showering and washing Fresh air Internal doors Steam, vapour Cooking, eating, food Smells

Table 26: Main fieldwork deductive (a priori) codes

Access to help		
Domestic practices	- Occasional practices	
	- One off events	
	- Routine practices	
Environmental and energy awareness		
Making sense of technology		
Previous experience		
Themes from Schatzki	- Ends: Domestic practices relating to ventilation	
	- Non-human entities affecting practices	*Living entities*
		Non-Living entities - constraints

Table 27: Main fieldwork inductive codes

Main fieldwork inductive codes (listed alphabetically, levels 1 & 2 only)

Abstract concepts	Avoiding hassle, getting by	**Spatial configuration of ventilation and heating elements**	Air conditioning
	Feelings		Air handling unit, fans
	Fighting their corner		Boost function
	Financial issues, costs, money		Breathing wall
	Practicing what s/he preaches		Doors
	Saving resources		Ductwork
	Talking with others		Electric fans
Environmental and energy awareness	Bills		Filters
	Climate change		Heating systems
	Energy		On/off switch
	Environmental awareness		Rooflight
	Green lifestyle		Sensors
Non-residential beliefs about performance of the homes			Site geometry, orientation
Social practices	Consultants' practices		Vents
	Interacting with residents		Windows and curtains
	Practices and ends[186]	**Temporal practices**	Past experiences
	Residents' practices		

[186] Key 'parent' code - see Table 28 for breakdown of 'child' codes

Table 28: Practices and Ends sub-codes

'Practices and Ends' sub-codes (first 4 levels)			
Comfort	*Indoor air quality*		
	Keeping out insects		
	Light		
	Noise, sounds, quiet		
	Privacy		
	Reasons for ventilating	Circulating air	
		Drowsiness	
		Filtering, cleaning air, NOx	
		Improving mood	
		Introducing new air	Air for breathing, oxygen
			Clean air, good IAQ
			Fresh air
		Protecting building fabric	
		Removing pollutants, bad air	CO2
			Dust
			Moisture
			Smells
			Smoking
			VOCs
	Staying comfortable thermally	Draughts	
		Providing a breeze	
		Staying cool	
		Staying warm	
		Stuffiness	
Communal areas			
Compliance and design targets	*Beyond minimum compliance*		
	Building regulations	Blower door tests	
		Part F	
	Code for sustainable homes		
	Design standards		
	Planning application		
	SAP and energy reports		
Constructing buildings	*Commissioning*		
	Construction, work on site, meetings		
	Demolition, groundworks		
	Detailing construction		
	Drying out		

	Installing ventilation system	
	Quality of workmanship	
	Snagging and defects period	
	Teamwork and communication	
	Working drawings	
Designing a sustainable scheme	*Airtight*	
	Assembling a design team	
	Choosing a ventilation strategy	
	Contractual arrangements	
	Design aspirations	
	Developing low energy exemplar or prototype	
	Fabric first approach	
	M&E activities	
	Regeneration	
	Simplicity, easy to understand & use, robust	
	Specification, sustainable use of materials	
	Specifying and sizing ventilation system	
Domestic practices	*Homemaking*	Home decorating and improvements
		Looking for a new home
		Moving in, settling, living
	Housekeeping	Cleaning and tidying
		Cooking, eating, food
		Drying clothes
		Fixing and mending things
		Getting rid of waste
		Looking after pets
		Showering and washing
		Sleeping, waking up
	Storage, furniture, clutter	
Health and safety	*Staying healthy*	Allergies and asthma
		Disabilities and old age
		Illness, colds, pains and aches
		Mental health, psychological wellbeing
	Staying safe	
Interacting with nature	*Biodiversity, ecology*	
	Gardens, gardening	
	Views, parks and protecting nature	
Learning	*Buildings in use*	Feedback from residents
		Inspections and tours

		Leaning from completed projects
		Monitoring energy se
		Post-occupancy evaluation
	Skills and knowledge	Engaging with research, teaching and academia
		Interest in technology
		Interested in my research
		Skills
		Teaching, training
Looking after tenants	*Handover and information giving*	Face to face contact with tenants
		Information needed for residents to live comfortably
		Instructions on M&E technologies
		Tenants manual
	Helping tenants	
	Maintenance	
	Tenancy and tenure issues	
	Trying to change behaviour	
Work and play	*Leisure activities*	Exercising and active play
		Going on holiday
		Having visitors
		Praying or following faith
		Relaxing
		TV, radio and consoles
	Running a business	Directing a firm, management and HR
		Marketing, awards and admin
	Working, studying and volunteering	Studying and school
		Working and volunteering
		Working nights

Table 29: Extract from framework matrix

	G : Rooflight	F : Electric fans
Ali	They didn't have any means of opening the rooflight in the first summer and found it 'oppressively hot' but once they had control of the rooflight it was much better. They find it quite hard to reach (he has mobility issues & was quite short) They open it when cooking.	No relevant references (but has single room A/C unit)
Sabeen	Hallway one open a lot during the summer. She remembers being told to open the rooflight during the summer to night cool the space but her and her 2 daughters are afraid of letting in bugs and she things this would affect their sleep. The stick was left hanging off the opening which is where they leave it when it's shut.	Use electric fans 'all the time' during summer to cool down. It is very hot and stuffy and then find it hard to sleep as they get sweaty, so the fan's on constantly.

Fara	They have to climb on top of chairs or use the ladder to reach the rooflight in the bedroom. They like the air from the rooflight as its cooling and use that instead of windows and fans during summer because of the disabled child who likes to unplug things and to keep it away from the baby. They've never used the one in the hallway, even though they have the pole because it's so high up it would be hard to change if the window broke so they don't' use it (even though they know the neighbour does). I wonder if this is because of their experience with the window getting damaged while they were away on holiday and they're concerned the same thing might happen here. The RSL have been round to show them how to open it but they asked them to close it again!	They have an electric fan for each room which they use during summer, mostly at night. They use the fans in combination with windows because granddad doesn't like having a fan in his room and uses the window and they don't have one near the baby either (So I estimate this means three fans in total - for each bedroom excluding grandfather). She says the house is nice and cool during summer but this could be because they are using the fans. They had problems with mould in a previous home which may explain why they are so keen on airing.
Karen	They open them during the summer (especially the one above the landing) but are careful about how far they open them (especially the bedroom one) as rain can come in. She mentioned that one of the neighbours houses got 'very wet' after leaving the window open all night. I wonder whether Fara had heard about this too. They check to see if there's going to be any rain and they close the rooflight if they anticipate any. She said the RSL were investigating the angle that the window could be opened without letting water in.	Use fans upstairs at night (and considering purchasing a/c) She feels that the fans help cool her down by she feels like it's 'recycled air' which she doesn't like so much.
Pamela	They generally open it in the summer and not very often in the winter - only if they burn something in the kitchen. She struggled a bit getting the pole off the rooflight as it had got stuck. She implied this was a regular occurrence!	They use 'big fans that just ventilate it more' and think they are 'brilliant'. Also using one a/c unit and windows and rooflights.

Name	Sources	References
Environmental and energy issues	0	0
Non-resi beliefs about how houses are performing and being (	25	171
Comfort	6	7
Indoor air quality	0	0
Keeping out insects and spiders	12	24
Light	42	73
Noise, sounds, quiet	35	87
Privacy	11	16
Reasons for ventilating	16	32
Drowsiness	1	1
Filtering, cleaning air	0	0
NOx	2	2
Improving mood	2	2
Introducing new air	41	125
Air for breathing	4	4
Bringing in fresh air	26	73
circulating air	9	12
Clean air, good IAQ	10	14
Provide fresh air	6	8
Providing oxygen to breathe	3	5
Protecting building fabric	3	5
Removing pollutants, bad air	11	15
CO2	3	4
Dust	17	34
Moisture	13	18
Condensation	30	67
Damp	14	15
Dehumidifiers	1	1
Humidity	16	19
Mould, mildew	36	73
Steam, vapour	21	31
Smells	38	84
Burning joss sticks or candles	3	3
Smoking	13	17
VOCs	4	4
Staying comfortable thermally	32	56
Draughts	25	30
Providing a breeze	5	7
Staying cool	65	191
Staying warm	67	261

Figure 67: Example of coding reference list (generated 04/04/14).

Appendix B.5: Example of diagrams showing resident's ventilation practices

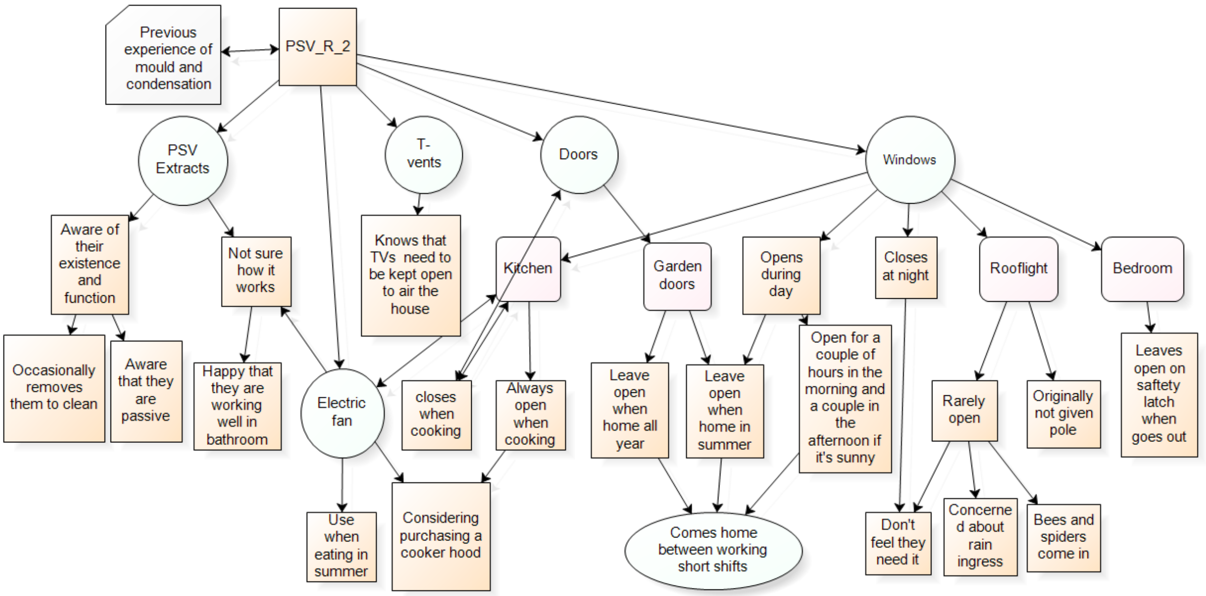


Figure 68: Example of diagram used during analysis, setting out each resident's ventilation activities in relation to the physical components (Maria, Case C)

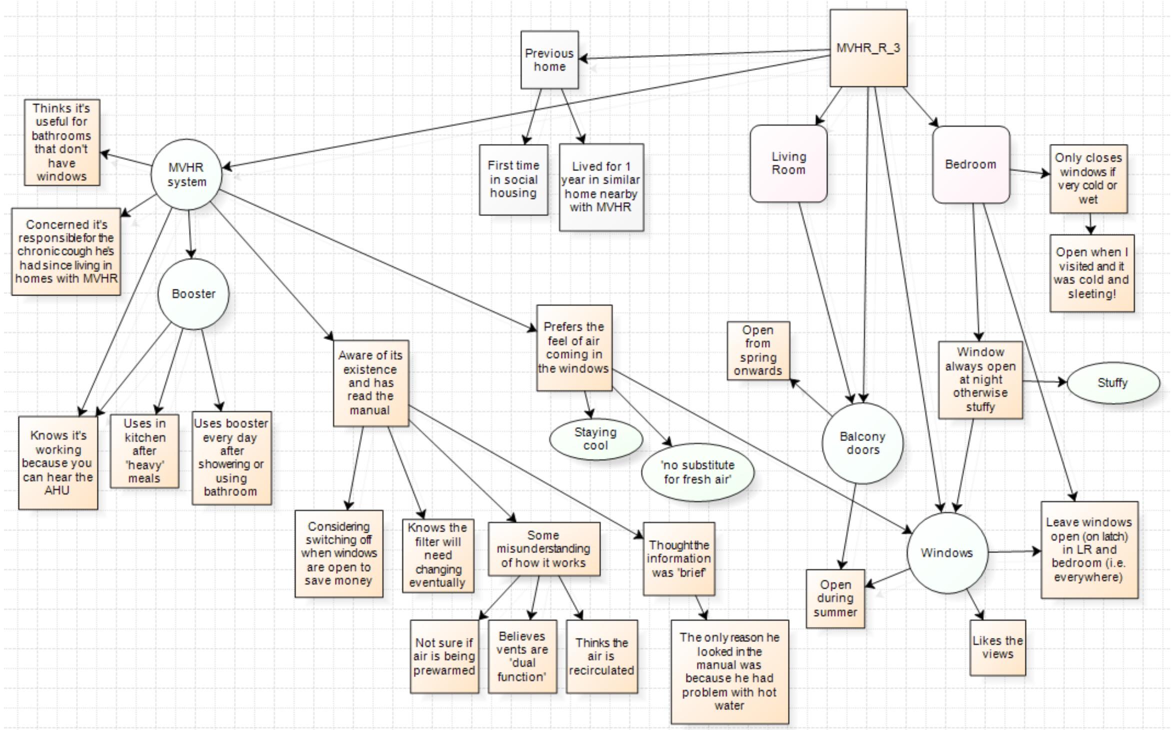


Figure 69: Example of diagram used during analysis, setting out each resident's ventilation activities in relation to the physical components (Anthony, Case B)

Appendix C. THE THREE CASE STUDIES

The documentation included in this Appendix forms the basis for the analysis presented in Chapter 5: The physical arrangement of homes with whole house ventilation.

This section describes each of the three case studies under the following headings:

Background

- Design concept and layout
- Sustainable design ambition

Building fabric and services

- Construction type
- Heating system

Ventilation system and strategy

- Ventilation system components and layout
- Windows and doors

Building performance (where available)

- Energy use
- Airtightness

This is followed by analysis of each resident at each case to show how this home deviates from the 'ideal' or designed configuration described in the first part of the chapter. Photos taken during fieldwork were analysed alongside the memos which were written immediately following interviews as well as while transcribing and coding the data.

Case Study A: Mechanical Extract Ventilation within Prototype Sustainable Housing

Background

Design concept and layout

This scheme comprises a development of 14 terraced and semi-detached houses, which were completed in 2005, and developed by a small, independent housing association (RSL) in the south-east of England (responsible for approx. 400 units). It was the first of three housing schemes commissioned by the RSL, and was intended to inform the development of a replicable model of sustainable, low-carbon housing. To meet this criteria, homes must be cost effective to build and comfortable to live in, as well as meeting ambitious energy performance and environmental impact targets (see next section). Each subsequent development incorporated improvements based on experience gained at the previous scheme. Much of the information provided in this section is reproduced from two reports[187] which document the POE work that was conducted at the site in the years following completion (Anon., 2012) (Anon., 2008).

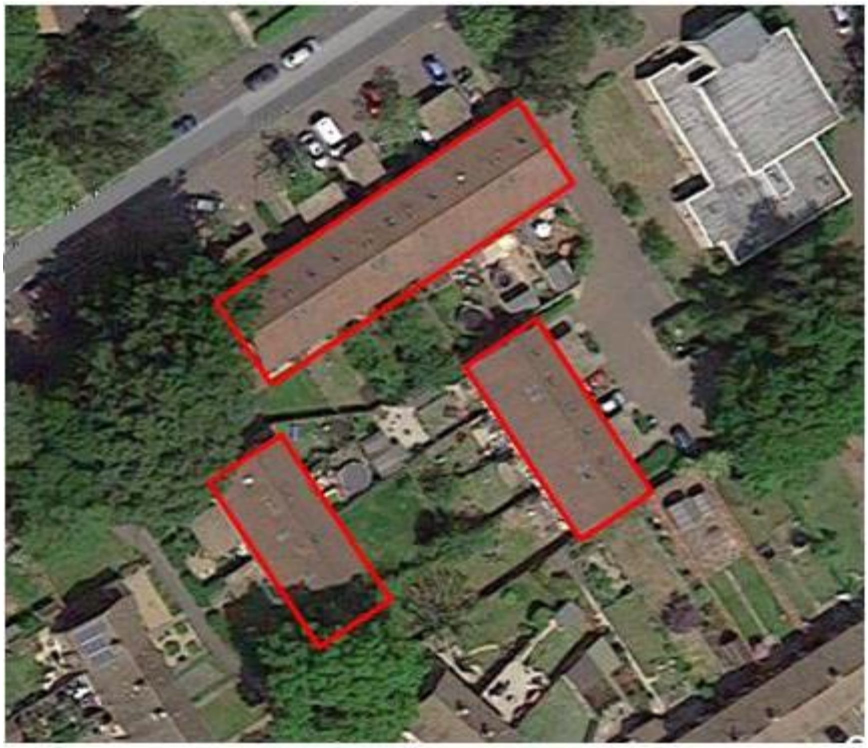


Figure 70: Aerial photo of Case A layout showing layout of the three terraces[188]

The RSL has a strong environmental agenda and strive to make sustainability *'the core of the organisation's business'* (Anon., 2008, p.5) and, based on this and a subsequent project, they won an award for their sustainable approach to housing development. The RSL appointed an architect and independent consultant for the project so that they could maintain control of specification and take a more flexible approach to the design process rather than handing over to a contractor at the tender stage. The contract was an adaptation of the GC/Works/1 design and build contract, which allowed for individual packages to be subcontracted as required.

The site comprises three terraces of 3, 4, and 7 two-storey units (Figure 70), as outlined in Table 30 below:[189]

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[187] Anonymised for confidentiality.
[188] From google maps (Google, 2015).
[189] See also Figure 32 (site plan) and Figure 33 (typical floor plan) in Chapter 5: The physical arrangement of homes with whole house ventilation.

Table 30: Case A Accommodation schedule

No. of units	No. of Bedrooms	Gross internal floor area (m^2) (GIFA)	Design Occupancy (no. of people)	Design Occupancy density (m^2/person)
6	2	80	4	20m^2/person
1	3	85	5	17m^2/person
4	3	86	5	17.2m^2/person

The key design objectives of the homes at Case A are listed below (reproduced from Anon., 2008)

- To provide 'future proof' homes that people want to live in now and in the future
- To be truly sustainable in social, economic and environmental terms
- To meet and attempt to exceed 'best practice' standards
- To be flexible and adaptable to changing needs
- To minimise ecological impact over lifetime
- To be affordable to run and manage, achieving best value over lifetime
- To become a replicable model that [the RSL] and others could develop further

The homes have a conventional appearance and layout, with kitchen and living areas located on the ground floor and bedrooms and a family bathroom upstairs. Some units have an open plan kitchen and living arrangement, while others have a separate kitchen and dining area. In the largest units, which have been designed to accommodate occupants with physical disabilities, one of the bedrooms is on the ground floor. An innovative feature of all the homes is the mezzanine storage space, which is located above the main bedrooms, from which it is possible to access the loft space via a low door. The mezzanine can only be accessed using a moveable loft ladder. A fixing to hang the ladder, when not in use, is provided on the first floor landing.

Sustainable design ambition

The project achieved the EcoHomes ‘Excellent’ standard with SAP 2001 values of 82-83. The scheme was designed around a ‘fabric first’ approach to construction, focusing on creating a well-insulated building fabric with an airtight envelope (later on, the third scheme also incorporated solar thermal). As well as reducing operational energy demand, the sustainability of construction materials was also considered. The development used only Forest Stewardship Council (FSC) certified timber and Polyvinyl chloride (PVC) free materials were specified throughout. Natural emulsion paints were used on internal walls, floors are linoleum instead of vinyl and wood wax was used on window frames. These features go beyond the minimum scope of compliance schemes such as Eco-Homes, Lifetime Homes and Secured by Design.

Triple glazing enabled larger areas of glass to be used at the same time as achieving sufficiently low u-values. This allows the homes to benefit from daylight which reduces reliance on electrical lighting. Low energy light bulbs were used throughout. Low water use WCs and showers were used, in combination with a compact plumbing layout to achieve reduced water consumption.

Building fabric and services

Construction type

The walls and roof are constructed from prefabricated timber frame panels, filled with cellulose insulation and sealed with an airtight membrane (Figure 71)[190]. The floor is suspended timber filled with cellulose insulation, finished with prefabricated plywood panels. Triple glazing has been used throughout. The window frames are timber on the interior and aluminium on the exterior which minimises maintenance requirements. A summary of design u-values is presented in Table 31.

Figure 71: The dwellings during construction (left) and after completion (right)

Table 31: Design U-values at MEV Site

Component	U-value (W/m^{2}K)
Floor	0.1
Walls	0.15
Windows	1.3
Roof	0.14

Heating system

Space and water heating are provided by a low-NOx (mono-nitrogen oxide) gas fired condensing boiler, with a system of TRV (thermostatic radiator valve) controlled radiators

[190] See Table 22 for a summary of airtightness figures obtained during pressure testing for all three cases.

throughout the house. Boilers are located at the back of the airing cupboard on the first floor landing. There is a digital thermostat on the wall in the ground floor hallway. Some thermostats have been replaced since the original installation so brand and model vary (Figure 72).

Figure 72: Photo of thermostats at Case A (Ali, left and Pamela, right)

Ventilation system and strategy

Ventilation system components and layout

The dwellings are fitted with mechanical extract ventilation (MEV) to meet fresh air requirements. During the summer, additional ventilation may be required to prevent overheating; windows are provided for this purpose. A central air-handling unit (Aerco) is located in the loft, connected to ceiling vents in the wet areas via ductwork (Figure 73, Figure 74). The loft is accessed from one of the bedroom storage mezzanines. The MEV continuously extracts at a low speed, and passive infrared detectors in the bathrooms and a boost switch in the kitchen serve to increase airflow to a higher rate, at times when greater concentrations of pollutants are being produced (Figure 75, Figure 76). Regular maintenance is required to remove dust and grease from the fans, grilles and filters (EST, 2006). Humidity controlled wall inlets in the habitable rooms draw in fresh air from outside. These are all located on external walls, behind a rainscreen cladding (Figure 77).

Figure 73: Air handling unit in insulated loft (Ali)

Figure 74: Ceiling extract vent in kitchen (Sabeen)

Figure 75: Passive infrared controlled ceiling extract vent in downstairs shower room (left) and on family bathroom wall (right) (Sabeen)

Figure 76: Boost button switch on kitchen worktop (left) (Fara)

Figure 77: Humidity controlled wall inlet in living rooms at (Sabeen, left and Fara, right)

Windows and doors

The houses have been designed with large areas of glazing to introduce natural light into the spaces.[191] There are several different types of window in each house as well as some fixed glazing panels. Below follows a description of the typical arrangement of windows and doors seen at the site.

Figure 78 shows the front elevation of a typical house. In the bottom-left of the image is the kitchen window. This comprises a small top-hung casement window beside a larger fixed glazing panel. Figure 79 depicts the kitchen windows from the inside. To the right is the front door with a large glazed vision panel. Just visible behind the timber porch is a smaller bathroom window. Above this, at first floor level is a typical bedroom window configuration. Here, two top-hung openable windows enclose a fixed glazing panel. Figure 80 shows three differently sized, yet compositionally similar bedroom window arrangements at one property. To the right is a top hung openable casement window to the bathroom (see Figure 81 for interior views). The exterior of the openable rooflight located in the front bedroom is visible in the roof. There is a second openable rooflight in the hallway above the first floor landing in each house (Figure 82).

The rear elevations also contain a large area of glazing. Figure 83 shows two different living room window and garden door arrangements. Common to both images is a centrally located door with a large glazed panel, and to the right of this door is a full fixed area of glazing. To the left of the door is a configuration of openable windows and glazed areas which varies according to the size of the room. The end of terrace homes have additional small windows where there is room available, as illustrated in Figure 84.

Across the scheme, internal doors were designed with a 10 mm gap under them to allow for the free passage of air between the spaces.

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[191] These may also increase solar gains to the internal spaces.

Figure 78: Configuration of glazing on typical elevation (left) and door (right)

Figure 79: Kitchen windows (Sabeen, left and Karen, right)

Figure 80: Windows in smaller (top left) larger (top right) and largest bedrooms (Fara)

Figure 81: Bathroom windows at (Fara, left and Karen, right)

Figure 82: Openable rooflights are located in bedrooms (Pamela, left) and above the landing (Fara, right) in each house

Figure 83: Living room door and window arrangement at A1 (left) and A2 (right)

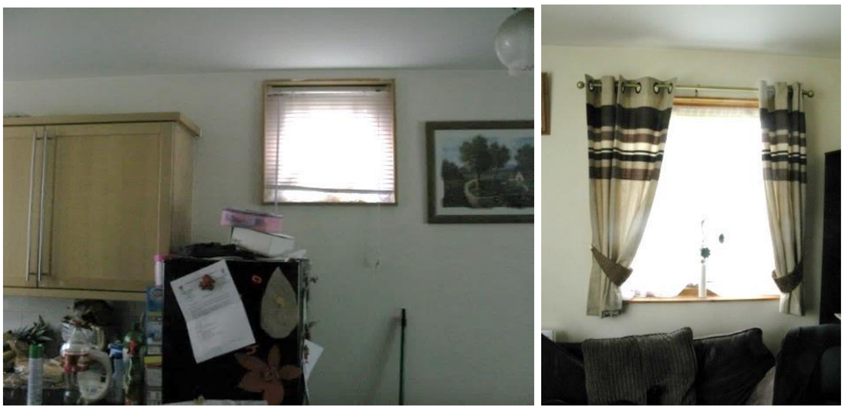

Figure 84: Additional openable window on side elevations in kitchen (Sabeen, left) and living room (Karen, right)

Building performance

Some funding was provided by the Housing Corporation to measure in-use energy performance and occupant satisfaction at the scheme.

Energy use

Energy data were collected for one full year, two years after the project was completed. Average gas consumption (heating and hot water) was found to be 70 kWh/m^2/y and 42k kWh/m^2/y for electricity.[192] [193] Water use was measured at approximately 90 litres per person per day. It is worth noting that occupancy density for this scheme is higher than that assumed

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[192] The total average figure of 112 kWh/m^2/y compares favourably to the primary energy target for Passivhaus of 120 kWh/m^2/y; however, the space heat demand is 15 kWh/m^2/y. Housing energy demand benchmarks proposed by (Pelsmakers, 2012) suggest a total figure of 165 kWh/m^2/y for a dwelling built to the building regulations (2013) and 144 - 151 kWh/m^2/y for a zero carbon dwelling.

[193] These graphs are reproduced from the MSc student dissertation based on a POE carried out at Case A and each show dwellings ranked according to gas and electricity use respectively. However, the house numbers on the x axis do not correspond to the same dwellings so it is not the case that the dwellings which use most gas also use the most electricity. The original dataset was not available.

by SAP (for these floor areas ranges from 32-38 m^2/person) and PHPP (35m^2/person)[194] assumptions.

Airtightness testing

One air pressure test was carried out for each of the four dwelling types. The results ranged from 2.96 $m^3/m^2.h@50Pa$ to 4.40 $m^3/m^2.h@50Pa$ (2.96, 3.38, 4.40 & 3.97) and were significantly higher than the design target of 1 m^3/m^2 (Table 22). There were some issues of poor quality workmanship which resulted in water damage to the air membrane; this led to the timber subcontractor's contract being terminated mid-construction. Remedial works were not completely successful in resealing the airtight barrier. Other sources of air leakage were found to be around inadequately sealed doors, windows, ducts and pipe penetrations.

Sample dwellings

This section presents a summary of each of the five households, which were investigated at this case. A brief description of the interviewee and any other residents living at the property will be followed by a description of any instances where property differs from the 'as designed' dwelling that was described in previous sections.

The location of each participant's home is marked on Figure 32: Case A site plan showing the five visited homes (scale 1:750).

Dwelling A0

The resident (Ali)

Ali, a 39 year old male resident was interview on 23/02/12. At the time of interview he had lived in the house for five years with his wife and three children. The dwelling is a mid-terrace house with three bedrooms. The family are the second tenants of the RSL-managed house; the first tenants moved out after six months. Ali has been unemployed for some time, owing to poor health (undisclosed physical and mental health problems), which started before he moved to this property. This dwelling has been used as an exemplar house by the design team and Ali is accustomed to welcoming visitors into his home. The interviewee's wife was in the house at the time of the interview, but was not interviewed. The property is rented from the RSL.

Deviations or modifications

The house has been fully furnished by the occupants, including a fitted carpet being laid in all the living areas. There are some instances where pieces of furniture are obstructing the wall air inlets. For example, in the daughter's bedroom, a bookshelf has been fitted in front of the vent. He complains that 'all the bad smells in the house seem to hang out here' which might be

[194] PhPP assumes 35 m^2/person whereas in the house with 11 occupants there is only 9.8 m^2/person.

connected to the obstructed vent. Another example is a wardrobe in the master bedroom which is also positioned in front of the wall inlet (Figure 85).

Throughout the house windows have been fitted with blinds. These include roller blinds in bedrooms and a Venetian blind in the master bedroom, a room which doubles as a home office (Figure 86). During the interview it was observed that a combination of the carpet fitted by the tenants and the fact that the floor surface has buckled and is now uneven, meant that, at least between the living room and the hallway, the 10 mm ventilation gap required by ADF is no longer present.

A freestanding air conditioning (AC) unit was found in one of bedrooms. Ali explained that this was purchased when his daughter had a fever, and that they did not use it often. It was also noticed that the mezzanine storage area above the bedroom was quite full, restricting access to the loft space (Figure 87).[195]

Ali also explained that when they first moved in they were unable to open either of the rooflights, but that a pole was subsequently provided when they complained to the RSL and that they now had control over the openings. A window was open in the two smaller bedrooms during the visit (Figure 86, Figure 88). The heating was set on the timer with the thermostat showing 22°C. Ali suggested that the heating wouldn't need to come on that day as the temperature would sustain itself at the set point. As the interview was conducted during February, on a day when the average temperature at the local weather station read 12.5°C, this is not certain. The original analogue thermostat was replaced with a digital model that was purportedly easier to use (Figure 4).

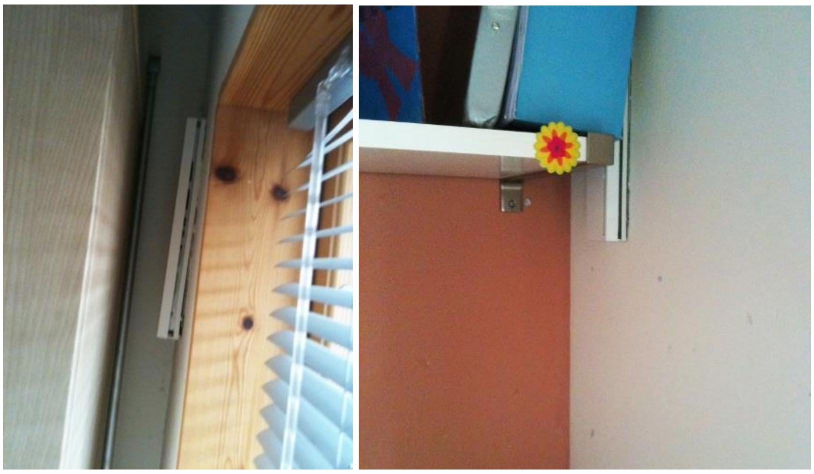

Figure 85: Pieces of furniture can obstruct the wall inlets (A0)

[195] It was later discovered, during the interview with Eddie, that this resident's home was one of the highest energy users, despite his interest in saving energy.

Figure 86: Venetian blinds in the home office (left) and roller blinds in the bedrooms (right) (A0).

Figure 87: Mezzanine storage area (A0)

Figure 88: Window open in daughter's bedroom (A0)

Dwelling A1

The resident (Sabeen)

Sabeen, a British female was interviewed on 14/05/13. She had lived at the two bedroom semi-detached property with her husband and two daughters since 2006. The property is rented from the RSL. Previously, they had lived with her husband's parents whilst waiting for a property to become available with this RSL, after several negative experiences living in poor-quality privately-rented accommodation in the same area. Both adults work full time and the children attend school. The interviewee's husband, who works nights, was asleep in the house at the time of the interview.

Deviations or modifications

The house has been fully furnished by the family. Net curtains have been fitted to most of the windows and remain drawn at all times, with secondary fabric curtains in bedrooms and living areas and roller blind to kitchen and bathroom windows (Figure 89). Sabeen had recently removed the curtains for cleaning and had been unable to replace the pelmet correctly so this is now missing. The bathroom blind was drawn. The small side windows in the kitchen and bedroom are fitted with venetian blinds (Figure 90).

Figure 89: Roller blinds over net curtains in kitchen (left) and bathroom (right) (A1)

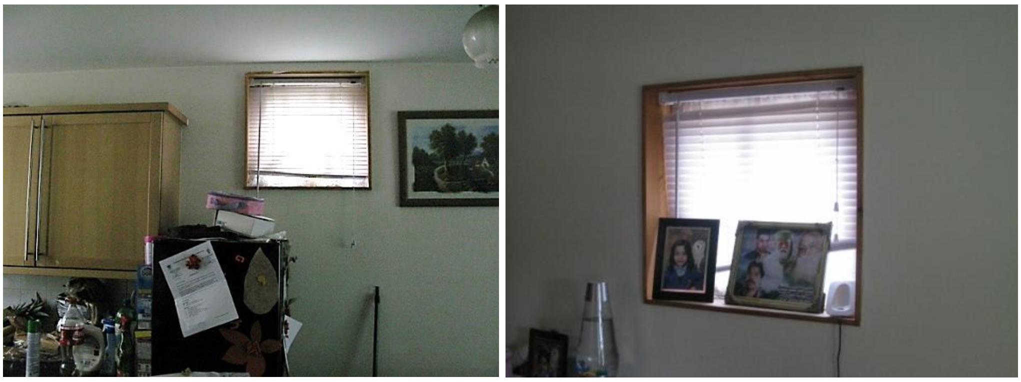

Figure 90: Venetian blinds to small windows in kitchen (left) and bedroom (right) (A1)

The pole for opening the rooflight is more or less permanently fixed to the rooflight in hallway. Only when the rooflight is opened does it come off and then hang in its place on the wall. On the day of the interview most of the windows where closed. Only the small top-hung window in the back bedroom was open (Figure 92).

As well as the central heating, this family have a small electric heater which the children like to switch on and sit beside when they get home from school. The family own several electric fans, one of which was visible in the mezzanine storage area. As is evident from the images, the house is quite full of possessions and clutter. There is a small patch of recurring peeling paint above the bath.

There was a persistent beeping throughout the interview. Sabeen explained that the battery on the fire alarm needed changing but that they'd changed it once and it had started again so they had just got used to it.[196] The sound is audible on the recording and occurred exactly every minute.

Figure 91 Electric fan in mezzanine storage area (left) and rooflight in hallway (right) (A1)

Figure 92: Bedroom windows (A1)

Dwelling A2

The resident (Fara)

Several members of a large family were interviewed on 14/05/13. The house has 11 inhabitants. There are three adults (a married couple and one of their fathers) with their eight children, ranging from an infant to 16 years of age. One of the younger children has a learning disability. The parents spoke little (father) or no (mother) English so the eldest child, Fara, a British-born female aged 16, acted as translator for her parents as well as participating in the interview herself. Several young siblings were also present during the interview. The house is a four bedroom mid-terraced property. The male works full time while his wife is a full time mother. The

[196] Interesting because it demonstrates the inertia of people to get things fixed and also the ability of people to block out and get used to things that are potentially very irritating

grandfather's occupation is unknown. The younger children attend school and the interviewee studies at a further education college. The family have rented this property from the RSL since it was constructed and had lived there for eight years at the time of the interview.

Deviations or modifications

Most windows have some kind of curtain, blind or covering. There are net curtains in the kitchen, living room and bathroom. Part of the curtain in one bedroom appears to be missing as only the supporting cable is visible. The large window in one of the bedrooms has been covered using a piece of fabric. The small, openable, window has been left exposed (Figure 93).

As there are 11 people living in a four bedroom house, the family have had to be creative with how they use the space, with the living room doubling as a master bedroom and pull-out mattresses used for the smaller children. There is little furniture in this house; in particular, there was no wardrobes. Instead, clothes are hung on rails suspended from the mezzanine storage area as well the living room door.

Figure 93: Bedroom curtains (A2)

Figure 94: Improvised clothes storage spaces (A2)

There is a digital prayer clock in the living room which sounds an alarm as a call to prayer. As well as displaying the current time and the time of the next prayer, the device also incorporates a thermometer and so displays the temperature in the room. According to the RSL (Eddie), the family have taped over their central heating thermostat to prevent their autistic son from tampering with the controls, something which had been causing problems. The RSL also mentioned that this family are using a fridge as a filing cabinet as it has a latch on it which the son cannot open. The family have several electric fans, one for each room according to the interviewee.

One of the bedroom window frames has been damaged when the window was left open accidentally while the family were away on holiday. As a result it no longer closes all the way. There were some small areas of mould around the window frame in one of the other bedrooms (Figure 95). At the time of the site visit (weekday mid-morning, springtime) the upstairs WC, the kitchen and two of the bedroom windows (facing the garden) were open.

The wall vent cover in the largest bedroom had broken and been taped back on, which may obstruct the air flow (bottom image, Figure 29). Laundry, drying in the garden, was visible.

Figure 95: Damaged timber window frames (A2)

Figure 96: Open window in bedroom (A2)

Figure 97: Wall vent cover taped back on (A2)

Dwelling A3

The resident (Karen)

A female resident called Karen was interviewed on 21/05/13. She lives at the three bedroom semi-detached property with her husband and three teenage children. Both adults work full time and the children attend school/college. This family were the property's first residents and were previously living with the father's parents nearby so witnessed the construction of the development. The interviewee was working from home on the day of the interview. The family have a pet dog who was also present during the interview.

Deviations or modifications

The family have furnished the house and it was quite full of furniture and other possessions. In particular, this home has a large number of electrical appliances, including large televisions in the living room and master bedroom and a computer and several games consoles in the sons' bedroom (Figure 98). The master bedroom furniture has been installed in such a way that the wall inlet is blocked by one of the wardrobes and access to the main windows is also obstructed (Figure 34). The airing cupboard is being used for storage rather than drying clothes and is extremely full, making access to the boiler virtually impossible.[197] The mezzanine area and the loft cupboard have both been used for storage.

Net curtains have been fitted to most of the windows. In the main living room window, these are split in the centre whereas in the smaller openings a single piece of net is used (Figure 101). There are fabric curtains to both living room windows and in the children's bedrooms (Figure 102). There is a roller blind to the family bathroom and a blackout blind in the downstairs shower room as well as in the kitchen (Figure 103, Figure 104).

Figure 98: Electrical appliances in living room (left), master bedroom (centre) and sons' bedroom (right) (A3)

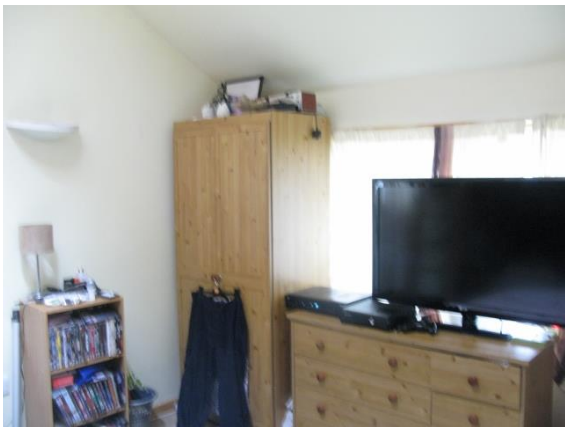

Figure 99: Wall inlet behind cupboard (A3)

Figure 100: Airing cupboard with boiler behind (let) and mezzanine area (right) (A3)

[197] However, as a result of this, moisture levels in the house could be lower than expected.

Figure 101: Living room curtains (A3)

Figure 102: Children's bedroom curtains (A3)

Figure 103: Bathroom (left) and downstairs shower room (right) (A3)

Figure 104: Kitchen windows (A3)

Additional white goods have been installed in a position that blocks access to the kitchen side window (Figure 104). The ladder to access the mezzanine storage was attached to the platform (for access) rather than hanging in the hallway. This may have been because the family were preparing for a holiday (Figure 105). There is an electric fan on the bedside table in the master bedroom; Karen spoke of 'fans', suggesting others were present (Figure 106). She also mentioned 'blowers' in the kitchen.

One of the children had made her own modifications to the space. In the daughter's bedroom the whole wall has been decorated with posters and cut outs of her favourite boy-band. This 'wallpaper' had been carefully fitted around the wall inlet (Figure 107). The cover to the wall vent in the boys' bedroom had come off. This was only discovered when the cabin bed was replaced, and a new cover has been ordered. The thermostat had been replaced by the RSL about six months before the interview as they had been unable to adjust it manually.

The pole for opening the rooflight is fixed to the rooflight in hallway. The dog's basket and bowls are located in the hallway at the bottom of the stairs (Figure 109). During the visit, which took place on a mild day in May, both the children's bedroom and the bathroom windows were open. The boys' windows was open a crack while the daughter's bedroom was wide open (Figure 102). The French windows in the living room were open during the first part of the interview and then closed by the Karen as the curtain was blowing into where we were sitting.

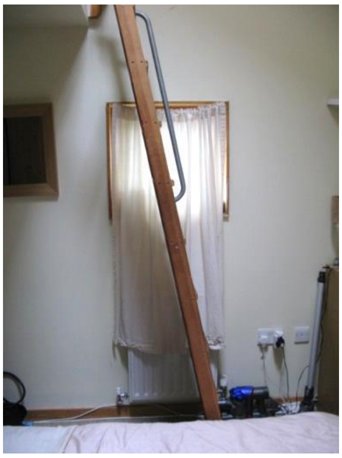

Figure 105: Loft ladder in master bedroom (A3)

Figure 106: Electric fan on bedside table (A3)

Figure 107: wall inlet surrounded by posters (A3)

Figure 108: Rooflight in hallway (A3)

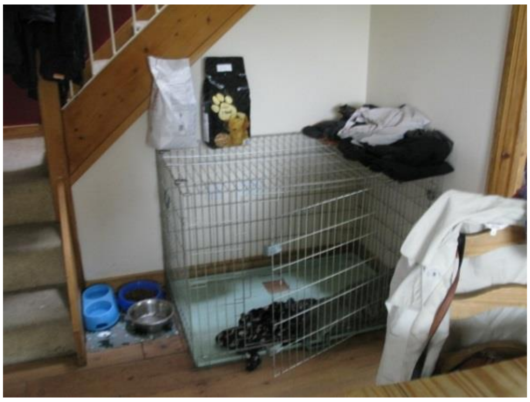

Figure 109: Doghouse (A3)

Dwelling A4

The resident (Pamela)

Pamela, a female resident of a four-bedroom mid-terrace house was interviewed on 24/05/13. She is a single mother, living with her two adult children and her teenage daughter who has a learning disability. Her elder daughter's young daughter also lives with them. The family were the property's first tenants and the interviewee is now looking to downsize as the children are starting to leave home. Also living in the house are the family's numerous pets; these include two dogs, two cats a pet rabbit and a snake. The interviewee works full time. During the interview two daughters and her granddaughter were also present.

Deviations or modifications

This house has a separate living room and kitchen. It has been furnished by the residents and a pre-pay meter has been installed for gas and electricity. Net curtains are fitted to the lower part of the kitchen windows with a roller blind above. The downstairs bedroom, belonging to one of the daughters has a window with the blind pulled down. The other daughter's bedroom has individual roller blinds on each window (Figure 110). The son's bedroom has net curtains in two sections over the window. In this room there are some clothes and a punch bag hanging off the mezzanine level. The pet snake's tank is also located in this bedroom. There is a roller blind over the net curtains in the master bedroom (Figure 113). In the living room, the fixed panel of glazing and the openable window have been fitted with vertical slatted blinds. The door is not covered (Figure 114). The small square windows in the living room and the kitchen are not covered (e.g. Figure 114). At the time of the visit only the bathroom window was open.

There was a freestanding cooling unit (air conditioning) in the master bedroom (Figure 115). The extract vents in the family bathroom and the kitchen were covered in a visible fluff (Figure 116). The booster button in the kitchen was locked in a 'depressed' position and did not appear to be working correctly (Figure 117).

Figure 110: Roller blinds in the two daughters' bedrooms (A4)

Figure 111: Son's bedroom (A4)

Figure 112: Kitchen windows (A4)

Figure 113: Master bedroom windows (A4)

Figure 114: Living room windows (A4)

Figure 115: A/C unit in master bedroom (A4)

Figure 116: Extract vents in bathroom (left) and kitchen (right) (A4)

Figure 117: Broken booster button (A4)

Case Study B: Mechanical Ventilation with Heat Recovery at a Large Scale Regeneration Project

Background

Design concept and layout

This case study comprises two apartment blocks, located on a much larger regeneration site in the South of England. The scheme comprises over 600 new homes, a large supermarket, a café and smaller retail units. The two blocks are each three storeys tall and contain 12 flats. Although they appear nearly identical in appearance they are in fact mirrored in plan. One of the blocks is managed by the local RSL (Block 1) whereas the other contains flats available for shared-ownership (Block 2). Blocks 1 and 2 were part of Phase 1 (of 4) and were completed in 2011. Construction of later phases was still underway while fieldwork was conducted; it is expected to be complete in 2017. Figure 118 shows an aerial view of the site before it was developed. The location of Phase 1 is in the larger of the areas outlined by a solid red line. A detail of the proposed units is presented in Figure 118, with Blocks 1 and 2 circled in red.

Much of the information provided in this section is taken from the following two reports:

- Design and Access Statement produced by the planning architect
- A Post-occupancy evaluation report produced by a third party research organisation (MVHR_POE_Consultant, 2014).

The regeneration project is being developed under a consortium which includes a major national contractor and housebuilder, the local council and a local RSL with investment from central government. Over 500 substandard homes were purchased under Compulsory Purchase Order (CPO) and demolished (MVHR_Contractor, 2014). The design team included separate architectural practices for the planning and delivery stages of the project, with little communication between the two. The buildings were procured under a Design and Build contract. The main contractor was also the developer.

The two blocks contain a mixture of one and two bedroom flats, as illustrated in Figure 119 and Figure 120. On each floor there are two, smaller, single-aspect flats and two larger corner flats with windows on three sides. The flats are quite compact, with open plan kitchen and living areas. The communal areas include storage cupboards, a stairwell (no lift), and an outdoor car park with refuse sheds.

The accommodation is summarised below:

- **Type 1:** 6 no. 2 bed, 4 person @ 68.8 m^2 (occupancy = 17.2 m^2/person)
- **Type 2:** 2 no. 2 bed, 4 person @ 67.5 m^2 (occupancy = 16.9 m^2/person)
- **Type 3:** 4 no. 1 bed, 2 person @ 46.5 m^2 (occupancy = 23.3 m^2/person)

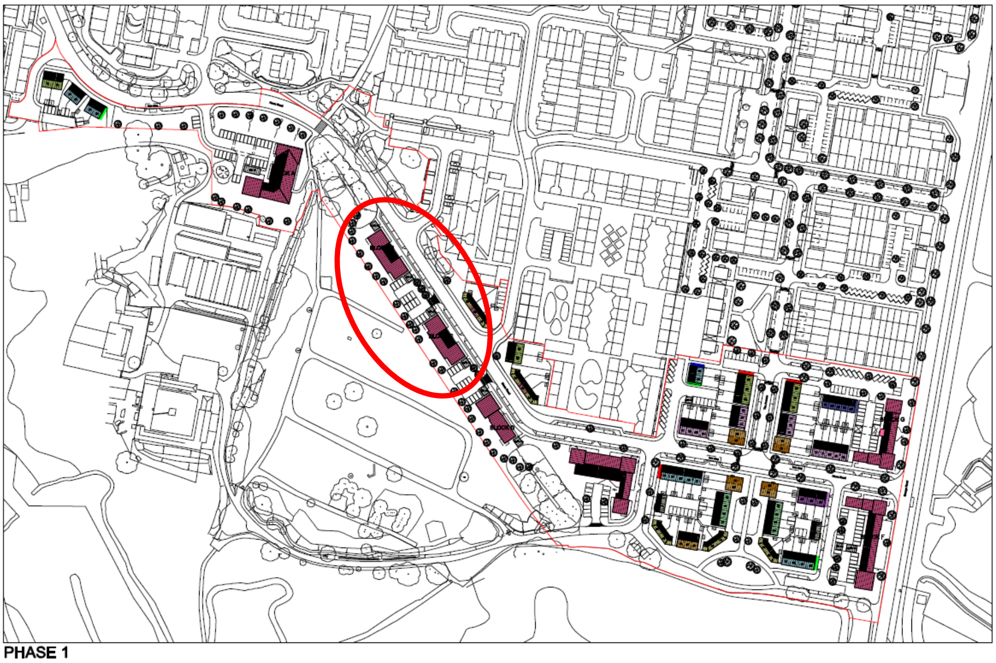

Figure 118: Phase 1 site plan

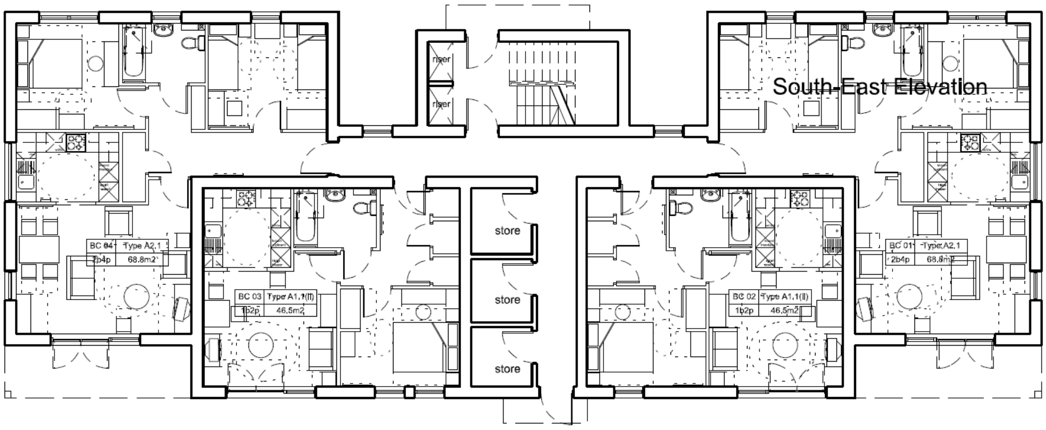

Figure 119: Ground floor plan (Block 2)

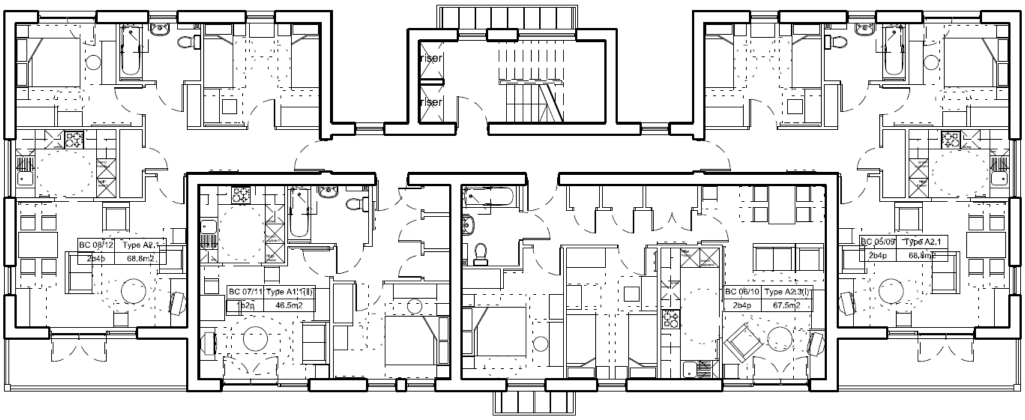

Figure 120: First and second floor plan (Block 2)

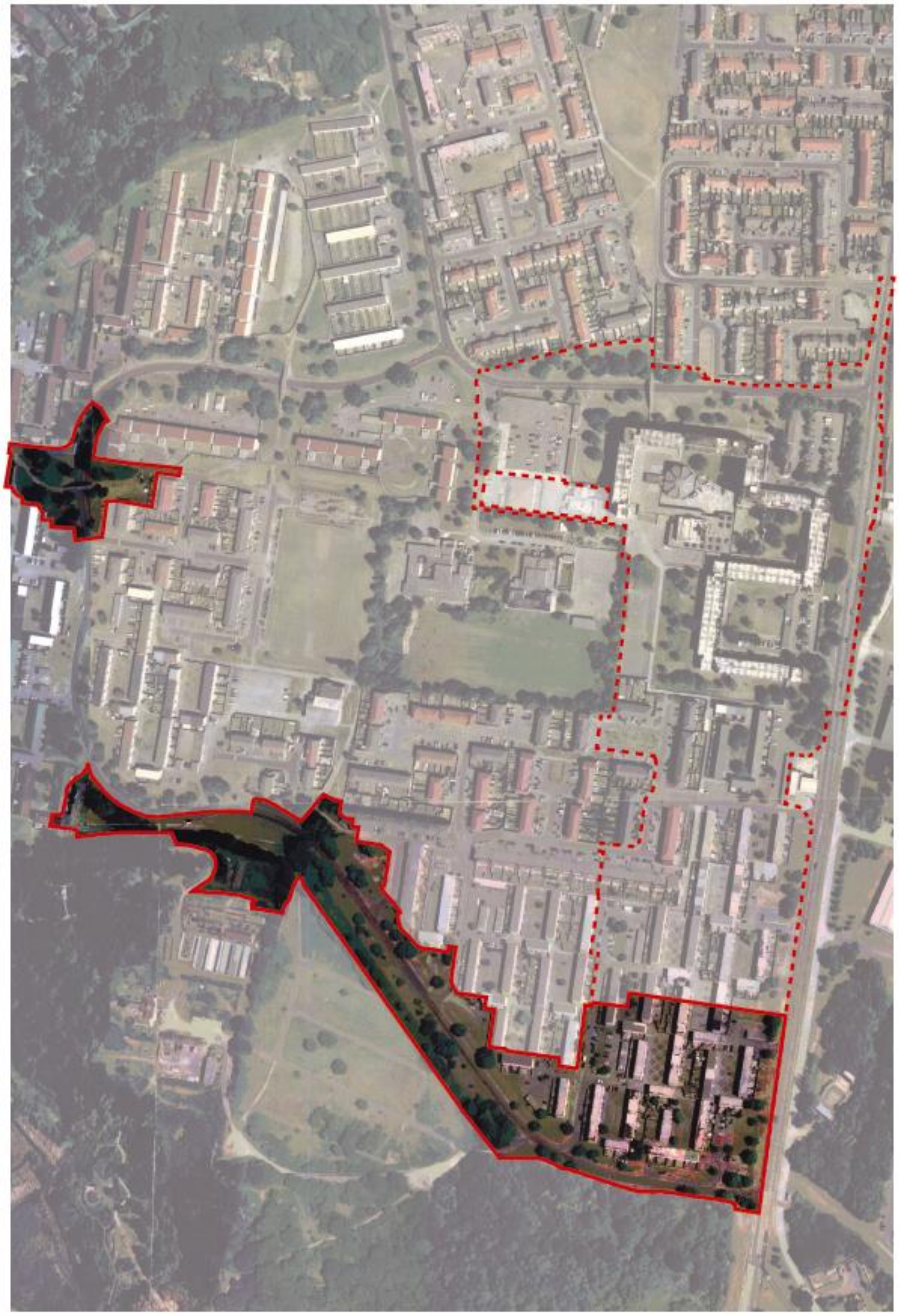

Figure 121: Pre-regeneration site plan

Sustainable design ambition

The main focus of this development was regeneration of a deprived area with very poor housing standards. Environmental sustainability was not such a strong driver for this project. Most of the homes across the larger scheme were designed to meet the minimum compliance at the time which is Code for Sustainable Homes Level 3 (CSH3). This sets out that buildings will consume at least 25% less energy than building regulations (2006 Part L). A stronger emphasis at the planning stage seems to be adherence to ‘Secured by Design’ standards, which relates to crime prevention. During the design process, additional funding was obtained to increase the specification of one of the buildings (Block 2) to achieve the Fabric Energy Efficiency Standard (FEES).

A fabric first approach was taken at both buildings; there are no renewables on the site. Instead, the emphasis is on providing an airtight and well insulated building fabric. Some of the measures proposed to achieve CSH3 are outlined in the Design and Access Statement and reproduced below. As the final specification document was not available it is unclear how many of these were actually installed:

- 75% of internal and all external lighting to be energy efficient
- Space provided to dry clothes naturally
- Cycle storage
- Low-flow appliances
- ‘good proportion’ of materials from sustainable sources
- Sustainable Urban Drainage (SUDS) to include porous paving instead of tarmac
- Internal and external storage provision for recyclable waste
- Low NOx boilers.

Building fabric and services

Construction materials

The buildings are of blockwork construction with 100 mm insulated cavities. Blown bean expanded polystyrene insulation (EPS) was used. Block 2 was constructed with double the insulation thickness in the external walls (200 mm) to achieve the FEES. The elevations are clad in buff brick, horizontal decking, and a light coloured render. Instead of using traditional mortar, ‘Thin-Joint’ masonry was used. This technique uses a glue-like substance, which dries almost instantly, to connect the blockwork; consequently, many more courses can be laid in a single day, accelerating construction. It also has the potential to reduce thermal bridging through mortar joints. PVC double glazing is used throughout.

As built U-values at one apartment in each block were measured using heat flux sensors. As built U-values at Block 2 were measured at 0.15 W/m^{2}k (floor), 0.18 W/m^{2}k (walls) and 1.5 W/m^{2}k (openings). As built U-values at Block 1 were measured at 0.15 W/m^{2}k (floor), 0.24 W/m^{2}k (walls) and 1.5 W/m^{2}k (openings). As built U-values were found to be higher than design assumptions.

Figure 122: Rear view of typical block

Figure 123: Front of typical block

Heating system

Space and water heating is provided by gas fired condensing boilers. There are radiators with adjustable TRVs in each room. A digital thermostat is located in the hallway of each property. The boilers are located in a cupboard in the living room. This location differs from that specified in the construction drawings, as the developer’s protocols changed during the course of the project; all new boilers must now be installed against external wall so that flues can be directly connected to the outside.

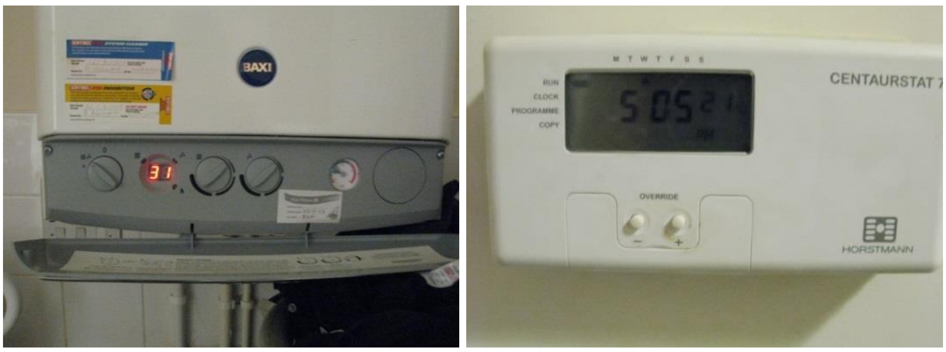

Figure 124: Boiler (left) and thermostat (right)

Ventilation system

System components and layout

The Ventilation strategy at this case study utilizes mechanical ventilation with heat recovery (MVHR). During the summer, additional ventilation may be required to prevent overheating; windows are available if required (there is no summer bypass mode). Each flat has its own MVHR unit (Titon HRV1 Q+), located in a cupboard in the hallway. Warm, vitiated air is extracted from wet areas (kitchen and bathroom) via vents, connected to a central unit via ductwork which runs within the suspended ceiling cavity above ground and first floor flats and inside the ventilated roof space for second floor flats. The air passes through a heat exchanger which recovers heat from the stale air and uses it to preheat incoming fresh air from outside, taken in via wall mounted louvres on the external elevation. This fresh air is then distributed to the habitable rooms via a series of ducts and vents.

MVHR is a relatively complex technology and requires regular maintenance to check that the system is working properly, as well as to clean the fans, filters and heat exchanger (EST, 2006). The manufacturer's specification and photos of a typical installed unit are shown in Figure 126 and Figure 127. The ductwork coloured in red denotes stale air being extracted from wet areas and then leaving the building via the heat exchanger. The ductwork outlined in blue brings in fresh air in from outside into the air handling unit and distributes it to the habitable rooms, which in this case comprise a living room and two bedrooms.

In each flat there is a boost button in the kitchen (Figure 125). This can be pressed at times when increased amounts of pollutants are being generated to increase the speed of fan. For example, it may be used when cooking or showering. The boost button is on a timer so that it stays on for about 15 minutes after being pressed and then switches off automatically.

This system has the potential to contribute to part of the dwelling's heating load, thereby reducing energy consumption. However, in order for the energy benefit to be realised, the dwelling must have a maximum permeability of 5 $m^3/hr/m^2$. The dwelling was tested post-completion and was found to have a permeability of 3.95 $m^3/hr/m^2$, just within the design target of 4 $m^3/hr/m^2$.

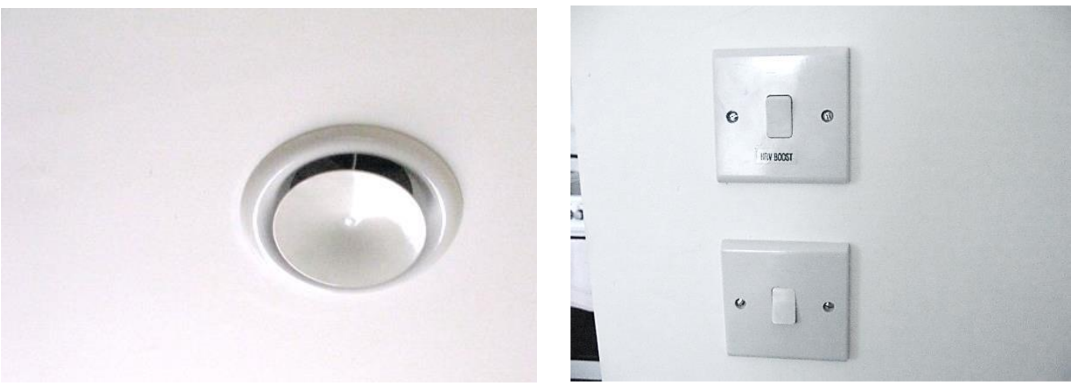

Figure 125: Typical ceiling vent (left) and boost switch (right, marked 'HRV BOOST')

Figure 126: MVHR unit (left, centre) and clean filters during commissioning (right)[198]

[198] These photos were part of the POE work undertaken and were made available to the researcher at a later date. The figure on the left demonstrates a poorly installed system with squashed ductwork.

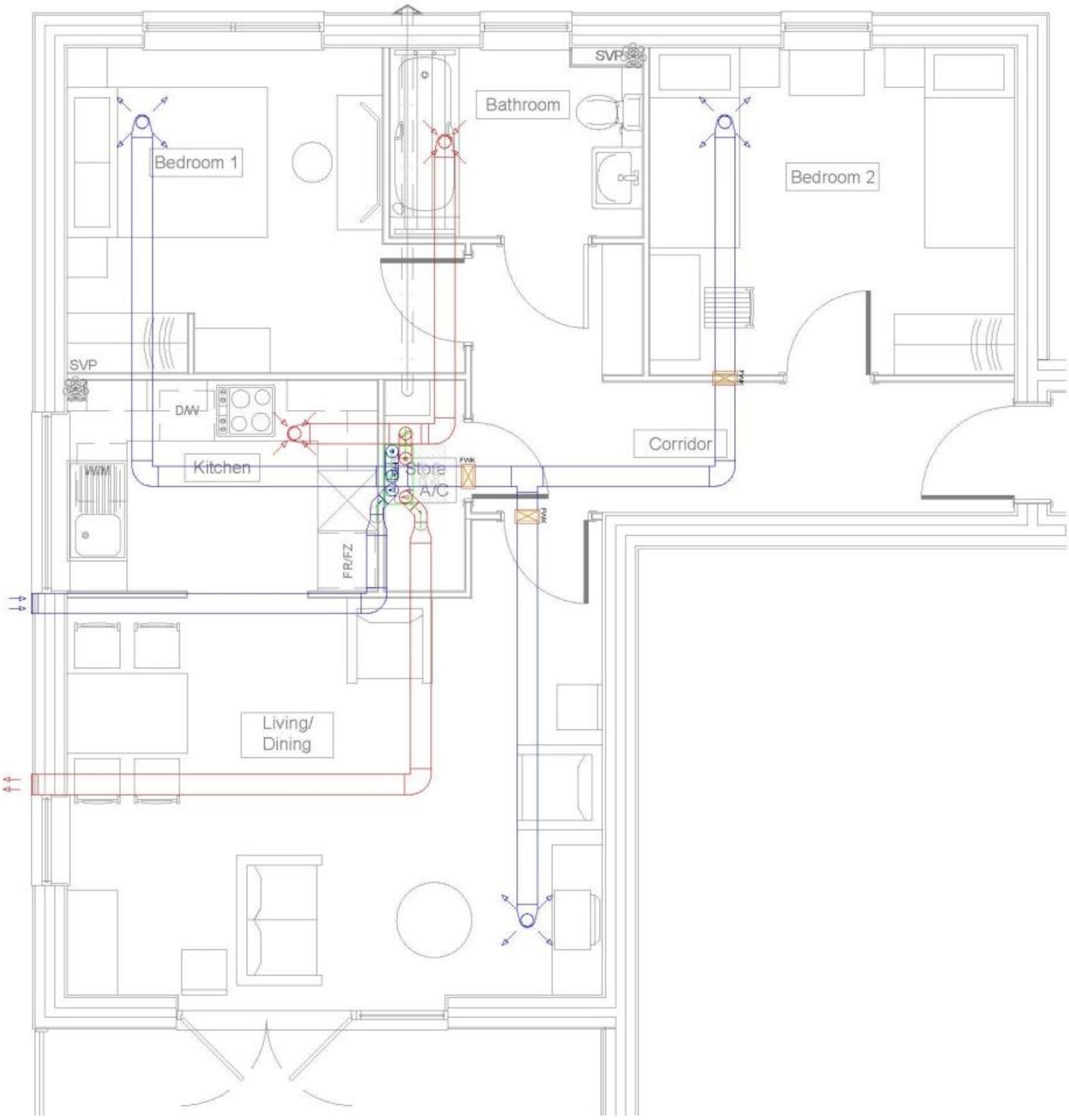

Figure 127: Manufacturer's MVHR Specification

Windows and doors

The flats have been designed to maximise natural lighting and to provide pleasant views on the countryside onto which they back; therefore, there are quite large areas of glazing. There are several different sizes of window in each flat as well as some fixed glazing panels. Windows are outward opening and operated using a 'tilt and turn' mechanism with a safety device fitted to restrict wide opening. All internal doors were designed with a 10 mm gap under them to allow for the free passage of air between the spaces. There is a notable difference in the arrangement of windows between the small, single aspect flats and the larger corner units. Typical window layouts at these two different dwelling typologies are described below.

The single aspect flats (1 and 2 bed version) are located to the rear of the building and face onto the park, in a south-westerly direction. Figure 128 shows the external facade of the one and two bedroom typologies. In the smaller flat there are just two sets of openings. On the left are two openable windows with glazed panels below them, both in the bedroom. On the right are the living room windows. These comprise two, full length inward-opening doors with a

Juliette balcony behind, and a separate openable window with a low level fixed panel of glazing. The right image shows a two bedroom window configuration. The living room has the same three part arrangement as the smaller flat. To the right is a full length glazed section with openable top window and fixed lower panel to the bedroom. The smaller window on the far right is to the second bedroom.

The corner flats are much larger and have windows and openings facing in three directions. In the living room are outward opening French windows alongside a window above a fixed glazed panel. The French windows lead out onto a covered balcony. There is another window on the side elevation in the living room. This comprises a fixed glazing panel with an openable window above. There are also two high level openable windows in the kitchen area (above the sink). In the master bedroom there is an inward opening single full length glazed door onto a Juliette balcony next to a fixed panel and open window section. There is a small openable window in the bathroom and another full length panel and window in the second bedroom (Figure 129).

There are also two windows on each corridor in the communal areas. These windows were fixed shut at all times during fieldwork but appear to have an actuator fitted to them for automatic control (Figure 130). Glazing ratios were calculated as part of the POE study, and are reproduced in Table 32 below. The figures suggest that flat types 2 and 3 may suffer from a lack of natural light but may also be susceptible to overheating, especially given that they can only take advantage of single-sided natural ventilation for cooling.

Table 32: Glazing ratios

Flat type	Glazed area (m^2)	Glazing as proportion of external wall area	Glazing as proportion of internal floor area
1	15.8	20.1%	22.6%
2	9.6	28.3%	13.7%
3	6.2	28.1%	13.3%

Figure 128: External elevation of single aspect 1 bed flat (left) and 2 bed version (right)

Figure 129: Side and front elevations of corner flats

Figure 130: Window actuator in communal hallway

Building performance

A detailed POE was carried out at the site during and for two years following construction, to investigate the following areas:

- **Evaluation of design intent and site practices**: analysis of design and specification documents and interviews with key members of design and construction team
- **Building fabric testing**: blower door tests (air-permeability), co-heating test, in-situ U-value measurements and thermography
- **Evaluation of handover and occupant engagement:** interviews, review of handover information and building use studies (BUS) occupant survey.
- **Energy consumption monitoring:** Gas, electricity and water consumption were measured at all 24 flats. In addition to this, one flat in each block was monitored in greater depth to include unregulated loads and comfort variables (see summary of variables in Table 33).

A follow-on study into overheating is currently ongoing at 11 flats, after this was identified as a potential issues in these and other new build dwellings. Variables being monitored are internal temperature, RH, window opening and electricity, gas and water consumption.

Table 33: Variables measured at Case B site

Variable	Units	Variable	Units
Electricity	W	Heating (Flow)	l

Gas	m^3	Heating (W)	W
Water (m^3)	m^3	Kitchen left	open /closed
Balcony door	open /closed	Kitchen right	open /closed
Balcony door (RHS)	open /closed	Lights - Power 1	W
Balcony window	open /closed	Lights - Power 2	W
Bathroom	open /closed	Living	%RH
Bed 1	open /closed	Living	Temp °C
Bed 2	open /closed	Living window	open /closed
Bedroom	%RH	MVHR	W
Bedroom	Temp °C	MVHR - Return	%RH
Boiler - Power	W	MVHR - Return	°C
CO2	ppm	MVHR - Supply	%RH
Cooker - Power	W	MVHR - Supply	°C
DHW (Flow)	l	Sockets - Power 1	W
DHW (W)	W	Sockets - Power 2	W
		Water	m^3

Some key findings of the POE work are summarised below. Much of the information in this section is compiled from published factsheets produced by the POE consultants as well as an as yet unpublished overheating report.

Energy use

Airtightness and ventilation commissioning

All air pressure tests carried out shortly after construction ended complied with the target of 4 $m^3/m^2/h$@50Pa. However, it is not clear from the documentation whether they were less than the 3 $m^3/m^2/h$@50Pa recommended to make MVHR worthwhile over MEV or other systems (Lowe, 2000). A second round of airtightness testing was carried out at eight flats in 2012; it was found that permeability had increased by 19-54% so that values now range from 4.95 $m^3/m^2/h$@50Pa to 5.95 $m^3/m^2/h$@50Pa. At these levels, neither MVHR nor MEV are considered effective ventilation strategies, which is a cause for concern and suggest that initial pressure test results may have been inaccurate or falsified.

Flow rates at a number of units were spot checked and found to be much lower than required for compliance with Part F (0-5 l/s, as opposed to 8-13 l/s design targets). This is consistent with blocked filters which may have become full of building dust and not been changed since, as well as bent ductwork (see Figure 126). The POE uncovered that there was no summer mode enabled, despite the fact that this feature was present in the specification. These figures are a contrast to those provided in the initial commissioning documentation which was carried out by the ventilation manufacturer and supplier in February 2011 and reproduced below:

- Type 1: 14.3 l/s (21 l/s on boost)
- Type 2: 9.6 l/s (21 l/s on boost)
- Type 3: 13.9 l/s (21 l/s on boost)

Comfort

Comfort and satisfaction levels reported by the residents in the BUS survey were generally very high and all respondents felt that their needs were being met. Problems raised with the design include the need for an extractor fan in the kitchen, the inconvenient arrangement of plugs and sockets and the lack of balconies to some flats.

However, an analysis of the risk of overheating, found that some of the dwellings may be vulnerable to excessive internal temperatures during periods of hot weather. Internal conditions at 11 dwellings were evaluated according to TM52:2013 (CIBSE, 2013). Two of these 11 flats coincide with those investigated in this thesis: Block 1, flat B0 (Betty) and Block 2, flat B5 (Luke) (see Figure 70). TM52 outlines three criteria which can be used to evaluate overheating. The property will be classed as 'overheating' if two of the three criteria are not met. Of the 11 flats, only B5 failed Criterion 1, Criterion 2 was failed by one flat in Block 1 (on the ground floor, resident not interviewed) and four flats in Block 2 (three on the ground floor and one on the first floor, residents not interviewed), and Criterion 3 was passed by all flats. Therefore, according to TM52, flat B5, inhabited by Luke, is overheating beyond acceptable levels (in some cases internal temperature exceeded 30°C). The other comparable flat in Block 1 was not monitored so it is not possible to determine to what extent, if any, the FEES standard contributed towards this overheating. However, the highest internal summertime temperatures were observed in Block 2, in flat B5 (Luke) and in a flat on the first floor. The heating was not used during this period. This suggests that although the built fabric may have an effect on comfort variables, the actions of occupants in terms of shading, window-opening and appliance use will also influence internal conditions during the summer.

Sample dwellings

Figure 131 shows a site plan of the two blocks in relation to the street and surrounding infrastructure. A schematic diagram showing the location of each of the participants' dwellings is presented in Figure 132.

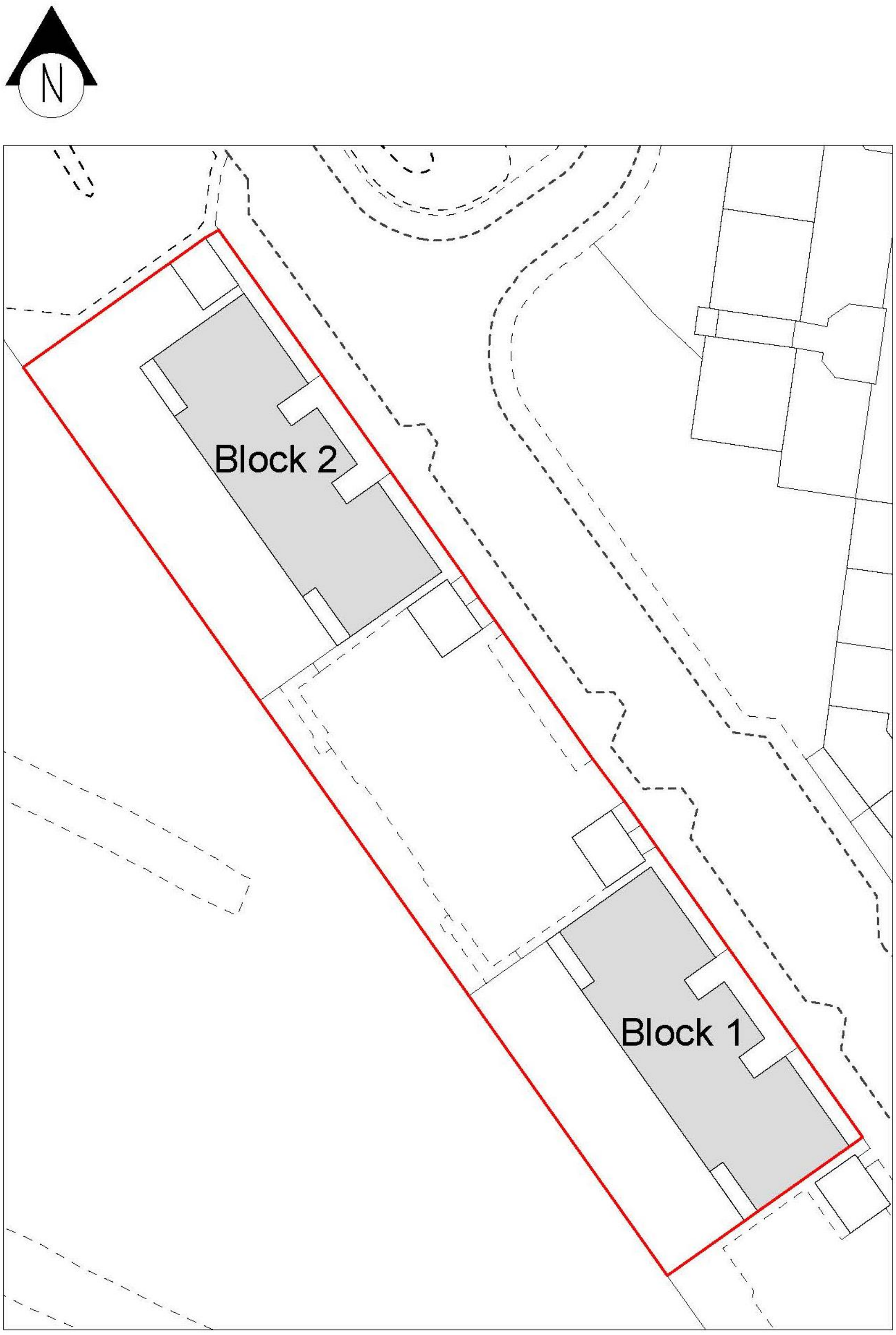

Figure 131: Site plan showing Blocks 1 and 2 (1:750)

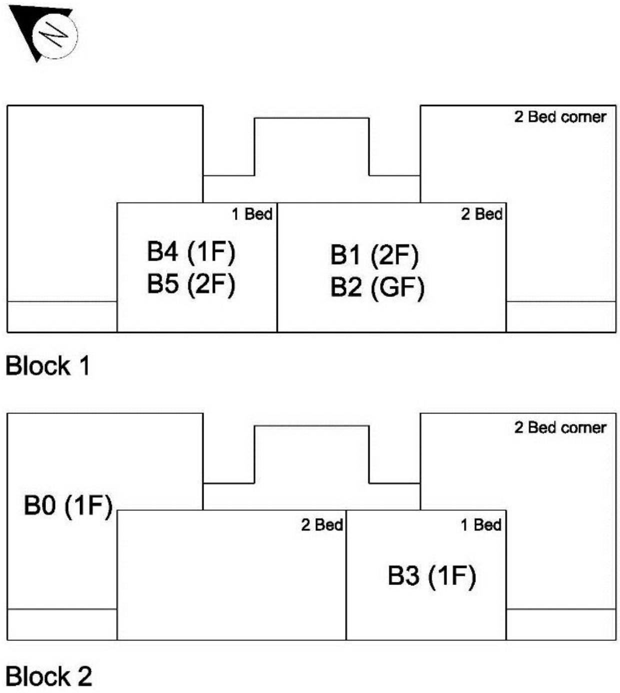

Figure 132: Diagram showing location of participants' homes (scale 1:400)

Dwelling B0

The resident (Betty)

The dwelling's first resident, an elderly woman who has lived in the flat since October 2011 was interviewed on 27/03/12. She is retired and has lived alone since her husband died, several years earlier. The flat is a two-bedroom corner unit, located on the first floor and to the north side of the block (SW, NW and NE aspects). Betty maintains the second bedroom for her middle-aged daughter, who visits occasionally. She is British and has lived in London and the South-East her whole life. Her previous home was a ground and first floor maisonette in one of the buildings that was demolished as part of the regeneration of the area. She part-purchased the flat under a shared-ownership agreement. This dwelling has been subject to detailed POE monitoring and Betty is very outgoing, cooperative and accustomed to talking to visitors about her home. As the interview was conducted in March, and Betty had only moved in six months earlier, she had not yet spent a summer in the flat at the time of the interview.

Deviations or modifications

The house has been fully furnished by the occupant. She has fitted a new electric cooker with a fan assisted oven. The extractor fan she had brought from her previous home did not fit so there is none. She also fitted carpet throughout the flat as she did not like the wooden floors. As she was not permitted to fit carpet in the kitchen she kept a piece of carpet offcut which she is using as a kind of rug in the kitchen area.

The compartmentalised recycling bin which was provided to all residents is still in the box under a pile of magazines behind the sofa. where it has been since she moved in. Instead, she has hung a carrier bag on the fridge door where she collects plastic bottles and uses a carrier bag on the kitchen floor for papers. She has bought herself a cylindrical pedal bin as she thought the general waste section in the one provided was too small. The new bin also has the advantage of having a pedal so she doesn't have to bend down so to use it. Her daughter has a lamp in the bedroom that would not fit an energy saving bulb, but the rest of the light fittings use energy saving bulbs, which were provided by the RSL.

The living room balcony doors were open during the interview. The Juliette balcony in the second bedroom was unlocked but closed. All other windows were locked shut. Betty explained that she had only recently worked out that she could open the windows beyond the latch setting after she was shown how to do so while being interviewed by the POE consultant. Previously, she was leaving windows closed as she did not see the point in opening them such a small amount. Net curtains have been fitted in the kitchen and second bedroom.

The heating was switched on during the interview. Figure 134 indicates a temperature of 21°C although this photo was taken after the Betty had explained how she can control the heating by using her thermostat and that the default setting was 18°C. The average external temperature this day was 12°C. There was an electric heater in the cupboard which Betty had brought with her from her previous home but had not felt she needed to use yet.

As part of the POE study, this flat has sensors and monitors in many of the rooms, which Betty refers to as 'eco-bits' (Figure 133).

Figure 133: POE sensors in living space with net curtain behind (B0)

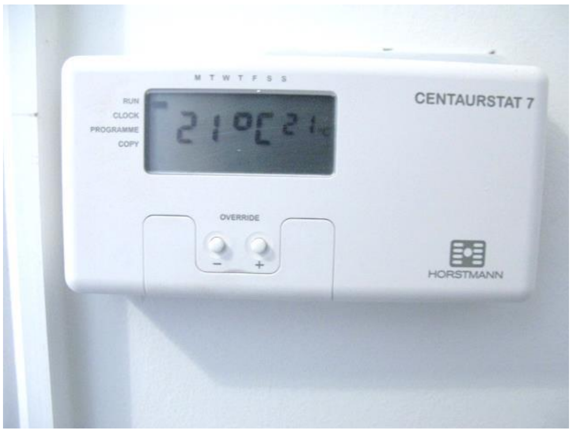

Figure 134: Thermostat showing 21°C (B0)

Dwelling B1

The resident (Paul)

A male resident, Paul, was interviewed on the afternoon of 20/03/13. He had lived alone at the two bedroom, second floor flat for one year before the interview. The flat is rented from the RSL and he is its first occupant. The flat is one of the singe-aspect units with all windows facing in a south-westerly direction. Paul works full time. His work is shift based and he works both days and nights depending on his contracts. He is a heavy smoker and was smoking throughout the interview. Paul also suffers from a medical condition which causes excessive sweating from the head. His previous home was one of the ones that was demolished during the regeneration. It was cold, had only single glazing and there were frequent incidents of antisocial behaviour in the building.

Deviations or modifications

The flat has been fully furnished by Paul. He did not have many possessions and everything was very tidy. Fitted carpets have been laid throughout. The TV was on standby with the light on during the interview. All windows were open on the latch setting, as were the balcony doors. Paul explained that because of his medical condition, he had to leave all the windows ajar at all times to maintain comfort. He also has an electric fan which he uses to blow cool air on his face when it's hot.

The thermostat read 21°C at this time, although Paul said he keeps it at 15°C. During the interview he demonstrated how he uses the thermostat to turn on the heating by pressing the button unit it clicks; this may explain why the photo, taken at the end of the interview, depicts a higher temperature. The average external temperature in the area on that day was 4°C so it is quite possible that the heating would come on occasionally to maintain the internal temperature at 15°C.

After the recording stopped we went into a bedroom to test whether the MVHR was blowing. After some encouragement, Paul climbed onto the bed and held his hand up to the ceiling vent and was quite surprised to feel a little bit of air - although he did not think it was that much.

Figure 135: Thermostat reads 21°C (B1)

Dwelling B2

The resident (Dan)

Dan was interviewed on the morning of 21/03/13. At the time of the interview he had lived alone in the ground floor one-bed flat for one year. His previous home was a three bedroom house, where he lived with his ex-wife and their son. He is British and local to the area. The flat is rented from the RSL and he is its first occupant. Dan works part time only as his physical health problems interfere with his ability to carry out his work in building maintenance. The flat is one of the singe-aspect units with all windows facing in a south-westerly direction.

Deviations or modifications

The flat has been fully furnished by the Dan, who has also installed a pre-pay meter for his utility bills. Net and fabric curtains have been fitted to the windows. The flat was quite sparsely decorated and is generally very tidy although a pile of clutter was obstructing the door to the cupboard containing the AHU (Figure 137). The compartmentalised recycling bin was placed between the kitchen and living areas (Figure 139).

The thermostat has been cracked since Dan moved in, so it is not possible to set the timer (Figure 136). He is *'still waiting'* for it to be replaced. The temperature on the thermostat read 20°C. All the windows were closed during the interview. Dan explained that this was because he had just woken up and that he was suffering from a cold. The patio doors are leaking and Dan was waiting for them to be fixed.

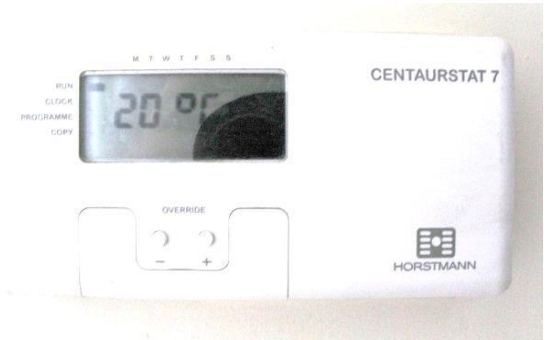

Figure 136: Thermostat with broken screen (B2)

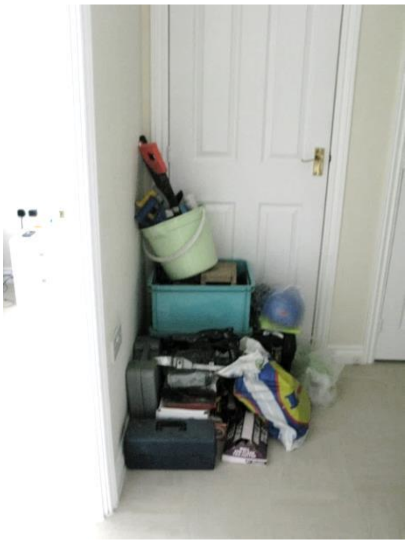

Figure 137: Clutter blocking door to AHU (B2)

Figure 138: Net and fabric curtains to living room window (right) (B2)

Figure 139: Compartmentalised recycling bin (B2)

Dwelling B3

The resident (Anthony)

A middle-aged male, Anthony was interviewed on the morning of 21/03/13. He and his wife had lived in the one-bedroom, first floor flat for six months when the interview was conducted. The flat was purchased under a shared ownership agreement and the couple are its first occupants. Anthony's wife was at home during the first part of the interview and then left for work. It is his first time living in social housing as he previously owned his own home, including one house which had a heated swimming pool. The couple are both relatively new to the area. The flat is one of the singe-aspect units with all windows facing in a south-westerly direction.

Deviations or modifications

The flat has been fully furnished and there are fitted carpets throughout the living areas. Venetian blinds have been installed in the living room to provide shading against the sun to prevent overheating.

In the AHU cupboard, ductwork is being obstructed by the couple's possessions. The condensate pipe has been appropriated as a clothes rail and has several hangers hanging from it. More clothes have been stored above the AHU so that the ductwork is being squashed against the wall. Originally ductwork was boxed in but this was found to be impractical in terms of maintenance, so the boxing was removed. The sofa had been positioned in a way that it completely blocks access to the boiler cupboard (Figure 140).[199]

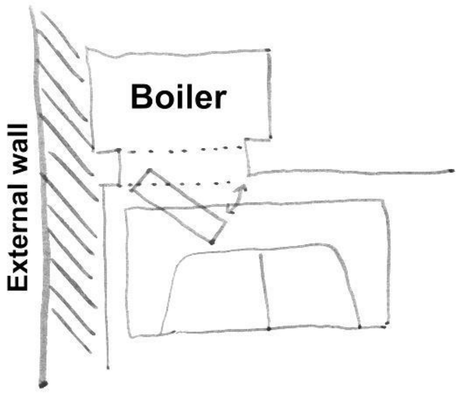

Figure 140: Sketch showing location of boiler cupboard and sofa (B3)

During the interview both the living room and bedroom doors were wide open. The bedroom window was also open. Anthony explained that the only reason the living room window was closed was because he was recovering from a cold. The thermostat is set to 18°C and the temperature during the interview showed 20°C (Figure 141). The interview was conducted on a cold day with an external average temperature of 4°C. Therefore, it is likely that during the interview the heating was on while the windows were open.

[199] The fact that location of boiler had to be amended at last minute means design not thought through as well as might have been perhaps - leading to clashes like this with furniture layouts.

Figure 141: Thermostat (B3)

Figure 142: AHU is being subsumed by residents' possessions (B3)

Dwelling B4

The resident (Steve)

A middle aged male, Steve was interviewed on the afternoon of 22/03/13. He had lived alone at the flat for 18 months when the interview was conducted. The flat is rented from the RSL and he is its first resident. Steve works full time. He is dyslexic and left school at a very young age. Consequently his literacy level is low and he struggles with basic reading and writing tasks. He is local to the area and previously lived in one of the homes that have now been demolished. He is a smoker and smokes in the flat.

Deviations or modifications

Steve has furnished the flat and has fitted carpet and fabric curtains. He has a new AV system and television in front of the radiator in the living area (Figure 143). The flat was generally clean and tidy. There was a laundry basket on top of a box in the AHU cupboard. A clothes horse was observed in the other hallway cupboard (Figure 147). There was a damp patch on the ceiling in the kitchen area (Figure 149). This was caused by water leaking from the bathroom in the flat above (belonging to Luke).

The boiler was switched off at the mains during the interview (Figure 144). Steve explained that he only switches it on when he is about to shower or to turn the heating on. The thermostat was set to 30°C; the current temperature in the room was 16°C (Figure 145). The average temperature on the day of the interview was 6°C. The TRV on the radiator behind the AV equipment was turned down to protect his '*gear*'.

The living room window was ajar during the interview, with the curtains partially closed (Figure 146). The carpet that was installed was a bit too thick so the living room door was hard to close. The required 10 mm gap was no longer visible though as the door was wedged open this is probably not a cause for concern (Figure 148).

Figure 143: Audio-visual equipment in living room (B4)

Figure 144: Boiler is switched off at mains (left), Corner of living room showing boiler cupboard on left and fabric curtains (right) (B4)

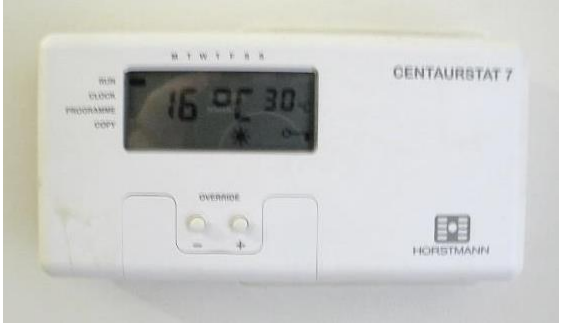

Figure 145: Thermostat set to 30°C, current temperature 16°C (B4)

Figure 146: Living room window ajar (left) with curtains part-drawn (right) (B4)

Figure 147: Laundry basket in MVHR cupboard (left), Laundry dryer in hallway cupboard (right) (B4)

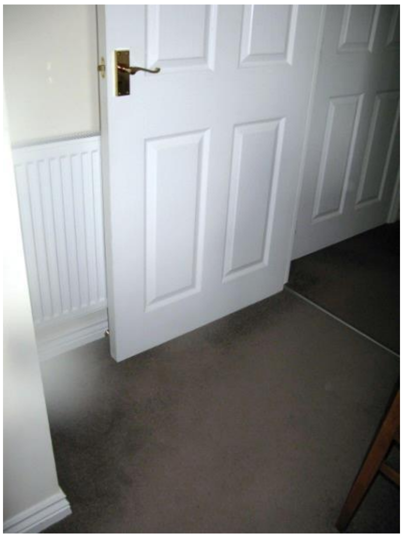

Figure 148: living room door scrapes carpet when opened and closed (B4)

Figure 149: Damage to kitchen ceiling from leaky bath in flat above (B4)

Dwelling B5

The resident (Luke)

A young man, Luke, was interviewed on the afternoon of 22/03/13. He had lived alone in the one-bedroom, second floor flat for 18 months prior to the interview. The flat is rented from the RSL. He is British and local to the area; his previous flat was owned by his parents and was demolished as part of the regeneration project. He works full time Monday to Friday.

Deviations or modifications

The flat was furnished by Luke and was quite full and a bit messy on the day of the interview. There were curtains on all windows. Luke had just got in from work and was cooking dinner during the interview. There was a dish in the oven which he checked towards the end of the interview as there was a smell of burning. The booster button was not being used.

All windows were closed during the interview as Luke had only just returned from work. The thermostat was set to 20°C and read 18°C during the interview. The average external temperature on this day was 6°C (Figure 155). The boiler was switched off and is only turned on when required to heat water. One of the control dials on the boiler is loose and so falls off whenever it is used (Figure 151). Luke keeps an electric fan behind the sofa for use during hot weather. The flat is one of the ones that is being monitored in depth for the overheating study so there are sensors attached to the windows and balcony doors (Figure 153).

The side of the bath had been removed by Luke as he was trying to fix the leak which was causing water to drip into Steve's flat, below. There was evidence of some mould around the bath taps and shower curtain (Figure 152).The AHU cupboard was quite full of boxes and other clutter although these do not appear to be interfering with the technology (Figure 154).

Figure 150: Kitchen with food cooking in oven (B5)

Figure 151: Boiler is switched off. Button on boiler control broken and falls off with use (B5)

Figure 152: Side of bath removed while resident tries to fix leak (left) some limescale and possibly mould are forming around the bath taps (right) (B5)

Figure 153: Sensors on balcony doors part of POE study (B5)

Figure 154: MVHR cupboard also used for storage (B5)

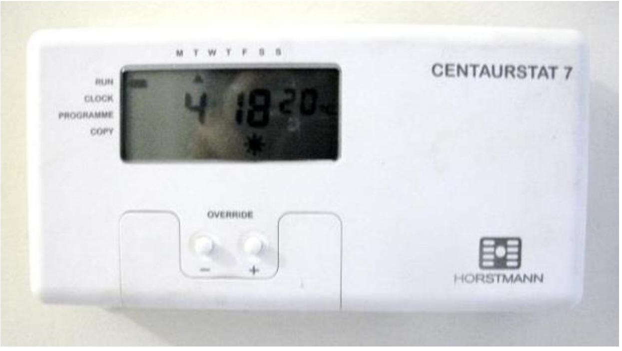

Figure 155: Thermostat (B5)

Case Study C: Passive Stack Ventilation at an Urban Terrace

Background

Design concept

This case study comprises a development of nine two and three storey terraced houses on a tight urban site at an urban location. The scheme was commissioned by a large RSL (36,000+ homes) and was completed in 2008. The project was conceived as an exemplar sustainable housing scheme by the RSL, who viewed the project as an opportunity to rebrand themselves as a *'green housing developer'* (Michael). After visiting a sustainable housing scheme developed by the local council, the RSL decided that they would like to appoint the whole design team, including the architect and contractor, to work on this project.

The development faces a children's play area and a car park which it shares with the Council-owned block of flats which it faces. The accommodation comprises nine 2-4 bedroom houses, each with a private front and rear garden, as detailed below:

- **Type 1:** 2 no. 3 bed, 2 storey @92 m^2
- **Type 2:** 2 no. 3 bed, 2 storey @101 m^2
- **Type 3:** 3 no. 4 bed, 3 storey @125-6 m^2
- **Type 4:** 2 no. 4 bed, 3 storey @174 m^2 (wheelchair accessible via lift)

Also part of the same development was a block of six apartments to the west of the houses which are not included in this research as they do not use passive stack ventilation. Much of the information provided in this section is taken from a POE study report conducted as part of an MSc dissertation in 2009.[200] In the next section, Figure 156 shows and aerial view of the development within its surrounding context. The houses and adjacent apartment block are distinguishable by their brown roofs.

Although the scheme was procured under a Design and Build contract, the design team had previously worked together on another project and therefore the architects had a much greater involvement in detail and construction work than would be typically expected with such an arrangement. Furthermore, as the contractor was appointed at the start of the project rather than through the usual pre-construction tender process they were able to contribute to early stage discussions, something which all parties agreed contributed to the overall success of the project.

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[200] The author and title have been anonymised to protect the identity of the research participants but extracts can be provided upon request.

Sustainable design ambitions

The scheme has won numerous awards for its ambitious sustainable design and achieved Ecohomes 'Excellent' rating. As well as following a fabric first approach to design and construction which focuses on a well-insulated building fabric and airtight construction, some renewables were also used as well as a number of other sustainability features relating to ecology and water use. The scheme was also designed around a number of mature trees present at the site, which had previously been a neglected area of woodland. It was important to preserve these and to continue to provide an environment for wildlife to thrive. The aerial image (Figure 156) shows the sedum roofs and trees at the site. The sustainability features of the scheme are summarised in Table 34 below:

Table 34: Sustainability features at Case C

Building Fabric	Water Efficiency	Biodiversity	Renewables	Miscellaneous
95% FSC certified timber	Rainwater harvesting	Stag beetle sanctuary	5 no. roof-mounted solar thermal	Compost bins
Super insulation	Low flush WCs (4 litres per flush)	Bat boxes		Bicycle storage
Green roof	SUDS paving (50% permeability)	Local plant species		Low energy light bulbs
Passive ventilation		Minimum tree cutting		Clothes dryer in bathroom
Natural paints				

Figure 156: Aerial view at Case C

Building fabric and services

Construction materials

The building fabric was designed to achieve low U-values, with design U-values of 0.19 W/m^{2}k (walls), 0.13 W/m^{2}k (roof) and 0.16 W/m^{2}k (ground floor), alongside timber-framed double glazed low-emissivity windows (U-value 1.5 W/m^{2}k). The houses were constructed using insulated timber-framed prefabricated panels. The insulation is recycled newspaper. The external wall finish is rendered panels and chestnut slats. Internally, natural paints are used to reduce VOC emissions. Each house has a sedum green roof and uses a water butt to harvest rainwater from the roof for use in the garden. Care has been taken to plant native species, for example leadwort in the garden. The roofs of the bicycle sheds are planted with lavender.

Figure 157: Exterior of Type 3 house (left) and detail of chestnut cladding (right)

Figure 158: Each house has a long garden (left) and a water butt (right)

A ‘breathing wall’ construction detail, incorporating ‘natural paints’ was designed for the external envelope to enable moisture to pass through and to avoid condensation.

Heating system

Each house has an A-rated gas condensing boiler which provides hot water for space heating and bathing. The five larger homes also have a roof-mounter solar thermal system which contributes to the hot water load. TRV controlled radiators are found in each room. The boilers are located in either a ground floor cupboard, the bathroom, or, in the larger units, in the utility room. A typical boiler interface and its instructions, which are printed on the inside of the cover to each unit, are shown in Figure 159. Maximum radiator and hot water temperatures can be set by adjusting the dials. Manual dial thermostats are fixed to the wall in the downstairs hallway to control space temperatures. Where present, the solar thermal tank and controls are located in a cupboard on the second floor (Figure 161).

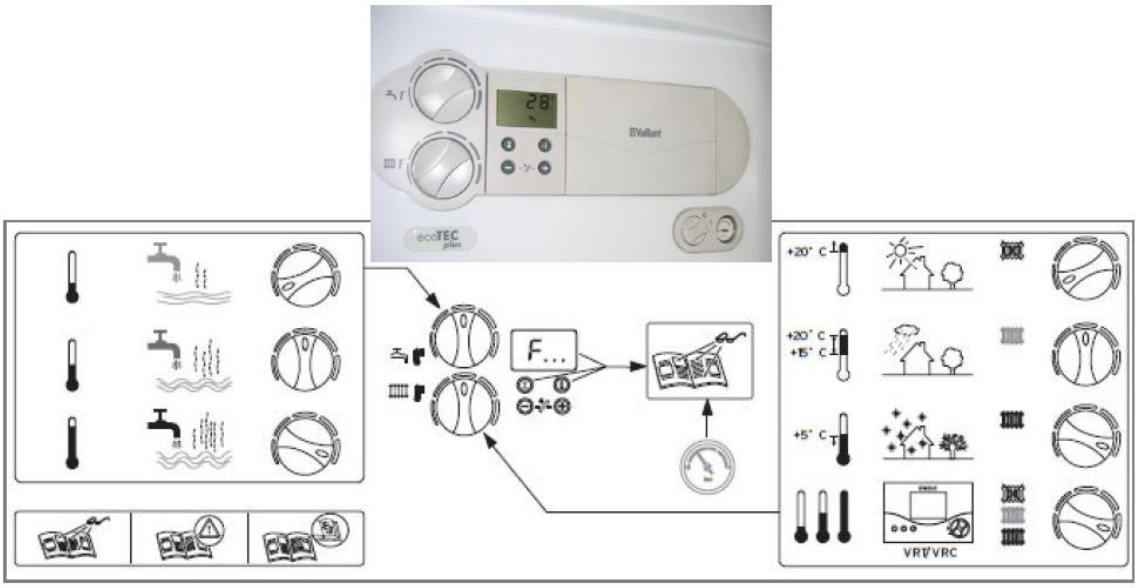

Figure 159: Boiler controls and instructions[201]

Figure 160: Thermostat (Sarah)

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[201] Image reproduced from anonymised student dissertation introduced in footnote 127 (section 5.1.3, (Anon., 2009)).

Figure 161: Solar thermal plant (left and centre) and controls (right)

Ventilation strategy

System components and layout

Fresh air is provided using PSV. During the summer, additional ventilation may be required to prevent overheating; openable windows are provided for this purpose.

The main components of PSV are ceiling or wall mounted extract grills which are connected to roof terminals via vertical, or near-vertical, ductwork (Figure 101, Figure 102). The extracts are located in all wet areas, which in these dwellings include bathrooms, kitchens and utility rooms (larger houses only). Fresh air is brought into the house through trickle vents, which are incorporated into the window frame in all habitable rooms (bedrooms and living areas) (Figure 166). The are no fans or electrical components in the system as it relies fully on the buoyancy effect created by the pressure difference between warmer stale air and cooler fresh air to drive the movement of air through the spaces. Although the ducting itself requires very little maintenance, it is important to regularly clean the grilles to prevent the build-up of grease, which may restrict the air flow (EST, 2006).

A permeability of approximately 8 $m^3/h/m^2$ was achieved at the site (Anon., 2009)

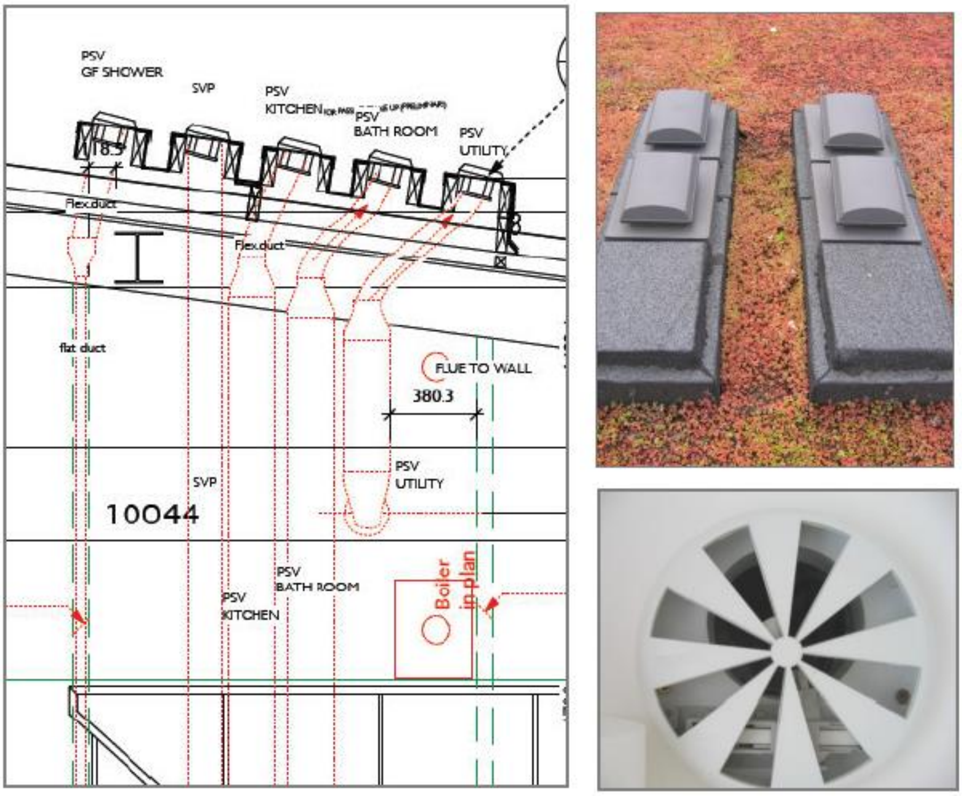


Figure 162: PSV ducts (left) connect extract grilles (bottom right) to roof terminals (top right)[202]

Windows and doors

The typical arrangement of windows at the four dwelling types are illustrated in Figure 163, Figure 164, and Figure 165. The front elevations face south and south-west, and the rear elevations face north and north-east. The windows are a combination of vertical, side-hung units in bedrooms and bathrooms and horizontal-pivot, bottom-hung units in the kitchens (Figure 168). All windows to habitable rooms have trickle vents (Figure 166). French windows, flanked by two full-length glazed panels, lead from the living area to the garden (Figure 167). Each house also has an openable rooflight in the top floor bathroom (Figure 169). Type 4 houses are a little wider and have a rear balcony at first floor level, accessible via a sliding door, next to a full length glazing panel. There is also an additional piece of fixed glazing beside the rear, op floor window. A 10 mm gap under each of the internal doors enables the movement of air through the house.

[202] The images are reproduced from the anonymised student dissertation referred to in footnote 127.

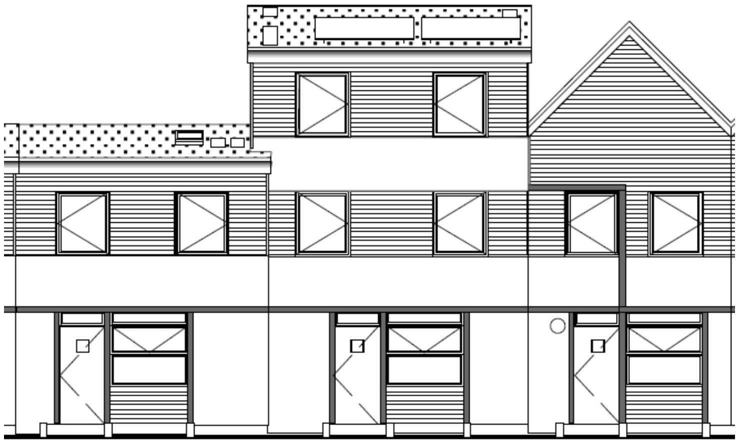


Figure 163: Front elevation showing window arrangement at type 1(left), type 3 (centre) and type 2 (right) houses

Figure 164: Rear elevation showing window arrangement at type 2 (left), type 3 (centre) and type 1 (right) houses

Figure 165: Front (left) and rear (right) of type 4 house

Figure 166: Example of trickle vent fitted in frame of living room window shown open (left) and closed (right)

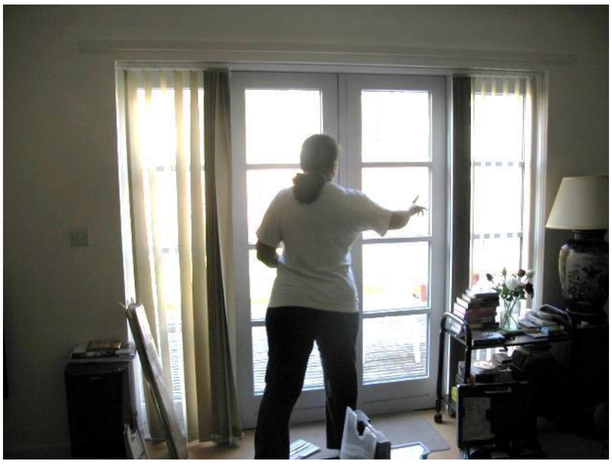


Figure 167: Living room windows and French doors to garden (Sarah)

Figure 168: vertical hung openable window with safety catch (left) and horizontal pivot window to kitchen (right) (Carla, type 4 house)

Figure 169: Rooflight in bathroom (Maria)

Building performance

A POE study was carried out by an MSc student. Data were collected from five dwellings, two of which overlapped with this research. Some of the key findings, documented in full in are presented below.

Energy use

Gas and electricity use and mean internal temperatures were measured over a five month period in 2008 (Feb-July). The house with the highest total energy consumption used almost three times as much energy as the house with the lowest consumption in this period. There was a much greater variability in gas than electricity consumption.

Table 35: Energy consumption data for period 27/02/08 to 13/07/08

Flat number	Flat Type	Mean living room temp (°C)	Mean bedroom temp (°C)	Gas use kWh/m^2/y	Electricity use kWh/m^2/y	CO_2 emissions kg/m^2/y	Total energy use kWh/m^2/y[203]
9	Type 3	24	25	146	20	38	171
8	Type 1	24	24	142	No data	No data	142 (gas only)
5	Type 2	23	23	82	27	29	109
2	Type 4 (Joy)	24	24	62	36	31	98
6	Type 3 (Sarah)	21	22	41	20	18	62

[203] These figures may be compared to the primary energy target for Passivhaus of 120 kWh/m²/y; however, the Passivhaus space heat demand is 15 kWh/m²/y which is much lower than the gas use shown in column five. Housing energy demand benchmarks proposed by (Pelsmakers, 2012) suggest a total figure of 165 kWh/m²/y for a dwelling built to the building regulations (2013) and 144 - 151 kWh/m²/y for a zero carbon dwelling. Most of these properties appear to fall within these limits.

Comfort

Figure 170 shows summer and winter temperatures at the monitored flats. From the winter temperatures we can see that some flats are being heated more than others. When evaluated alongside the gas consumption figures presented in the previous section, it is evident that the houses using the most gas are those that achieve the highest internal temperatures (flats 8 and 9) while the ones that use the least gas have the lowest average internal temperatures during winter (flats 2 and 6). The summertime graphs suggests that overheating may be an issue in these homes, particularly in the homes of Joy where living room temperatures exceed 28°C 72% of the time.

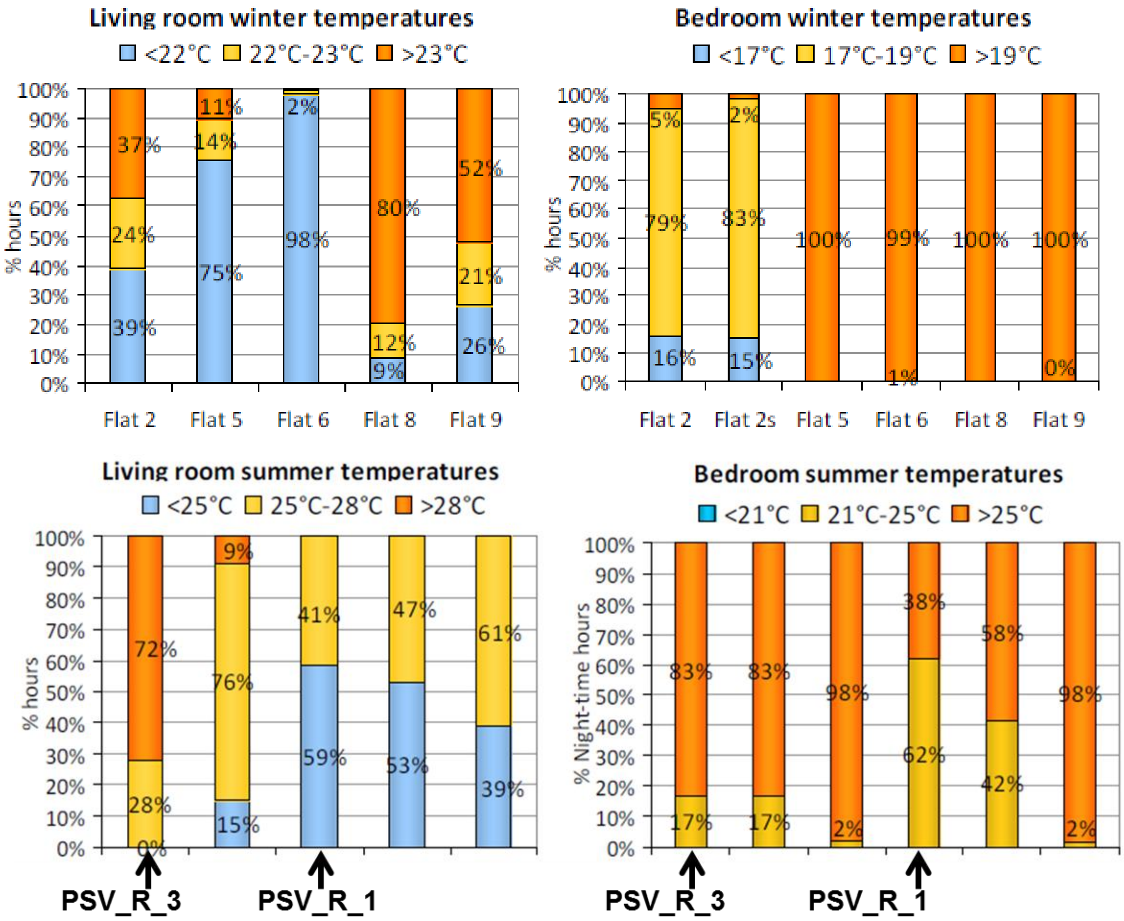


Figure 170: Distribution of winter (top) and summer (bottom) temperatures in living rooms and bedrooms

Sample dwellings

Dwelling C0

The resident (Carla)

Carla was interviewed on the morning of 23/02/12. She is middle-aged and has lived in the house with her husband and 4 children (now teenagers) since the buildings were completed (4 years). Originally from outside the UK, she has lived in in the local area for many years. The house is rented from the RSL. The family live in one of the larger four bedroom houses which has a lift for wheelchair access to all three floors (type 4). Carla's teenage son has a physical disability which prevents him from using the stairs. This house is an end of terrace property. The front of the house faces south-west and the rear elevation and garden face north-east. Carla had taken the morning off work to take part in the interview.

Deviations or modifications

The house has been fully furnished by the residents and was quite full of furniture and other possessions. There are cases where this could be interfering with the performance of the ventilation. For example, in the kitchen, there is a pile of books and boxes on top of the high level kitchen units. These are stacked up right below the ceiling extract grille, which is located beside the wall close to the corner of the room, in a way that they could potentially interfere with airflows of the stack gets any larger (Figure 171). In the master bedroom, the resident has moved the wardrobe in front of one of the windows in an attempt to reduce draughts; this has resulted in blocking out some of the light.

There are quite a lot of electronic items that the residents have introduced to the dwellings. These include a top-loading freezer and a running machine. Electric fans are used during periods of hot weather. A cooker hood has been installed in the kitchen. However, suggests that it was not plugged in at the time of the interview (Figure 171).

A number of windows were open at the time of the interview, despite the fact that the heating was on and the mean local temperature that day was 13°C (Figure 175). These included the first floor landing, a top floor bedroom and the kitchen (Figure 173). The bedroom and landing windows were on the safely latch, while the kitchen window was wide open. The trickle vent in the kitchen was open. On the landing, one window was closed while the other was open.

Two of the wet areas, the ground floor utility room and the first floor bathroom do not have access to an openable window. There are some small patches damp on the walls and bits of mould forming around the bath (Figure 172) which were not present in the top floor shower room, which had a rooflight in the ceiling (Figure 174). There are some outstanding repair works to the bathroom that the RSL have not completed. The plasterboard to the ceiling above the bath is missing as water had been leaking (Figure 112).

This resident has fitted a pre-pay meter for gas and electricity bills.

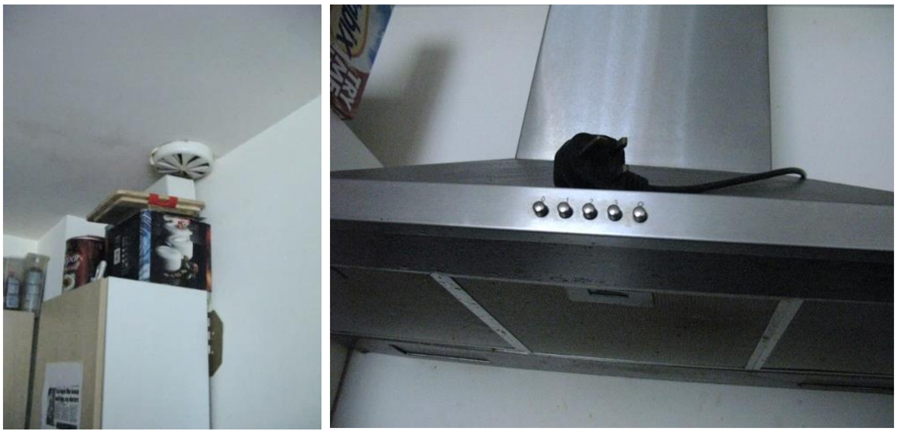


Figure 171: Ceiling extract fan in kitchen (left) and unplugged cooker hood (right) (C0)

Figure 172: Bath (left), missing ceiling covering in bathroom (centre) and shower tray (right) (C0)

Figure 173: Open windows in kitchen (left), landing (centre) and rear top floor bedroom (right) (C0)

Figure 174: Rooflight in second floor shower room (C0)

Figure 175: Controls for solar thermal heating (left) and boiler (right) (C0)

Dwelling C1

The resident (Sarah)

Carla was interviewed on 24/04/13. She is the property's first tenant and had lived there for five years when the interview took place. She lives in the house with her teenage daughter, her nephew (a young adult attending college) and her middle-aged brother. She has two adult children (a son and daughter) who are currently abroad. She had recently been bereaved and was also suffering from some physical and mental health problems. The house is one of the mid-terraced, smaller, four bedroom units (type 3). The front of the house is south facing and the rear elevation and garden face north. Sarah, her nephew and her brother all smoke. She explained that she only smokes outside on the doorstep while her brother smokes in his room which is at the top of the hose. Sarah does not allow her nephew to smoke in the house although she found evidence that he had been doing so during the walkthrough.

Deviations or modifications

The house has been furnished by the residents and looked well lived-in, with various possessions cluttering many of the surfaces. In the bathroom, this has resulted in the partial obstruction of the air extract grilles (Figure 176). Net and fabric curtains had been fitted to all bedroom windows to block out the sun (Figure 177). In the kitchen there are just net curtains and in the living area vertical blinds have been fitted to the fixed pane of glazing (Figure 178). There was a small clothes horse in the cupboard which houses the water tank and solar thermal plant. This was in addition to the clothes dryer which all houses have installed above the bath (Figure 179). This residents have fitted a pre-pay meter for gas and electricity bills. There was also an ‘Owl’ monitor in the kitchen which had been provided by the local council. The residents has installed a fixed shower above the bath to replace the flexible, handheld one that was there originally. There were some small patches of mould around the bathroom tiles (Figure 179).

Several windows were open during the interview. The windows in the master bedroom were both open on the latch setting, and the blinds were down. The second floor landing and bathroom windows were also open (Figure 180). However, the trickle vent on the landing was closed. Sarah mentioned that *‘sometimes the doors slam’* which suggests that windows left open might be creating a draft?

The thermostat was set to 24°C at the time of the interview (Figure 181). Sarah explained that she did not know what it was set on because of her poor eyesight. Average external temperature on this day was a relatively mild 15.4°C.

Figure 176: Residents’ clutter in front of extract vent (C1)

Figure 177: Fabric and net curtains in master bedroom (left and centre) and nephew’s bedroom (right) (C1)

Figure 178: Blinds in living room and net curtains in kitchen (C1)

Figure 179: Clothes horse in plant room (left), dryer above bath (centre) and small bits of mould forming on silicone around bath (right) (C1)

Figure 180: Windows open in bathroom (left), back bedroom (centre) and second floor hallway (right) (C1)

Figure 181: Manual dial thermostat set to 24°C (C1)

Dwelling C2

The resident (Maria)

A female resident, Maria, was interviewed on 29/04/13. She had lived at the mid-terrace, three-bedroom (type 1) house with her husband and two children for five years, or since the scheme was completed. Her young son was present at times during the interview. The family are tenants of the RSL. Maria and her husband are originally from [country with tropical climate]. Both work full time although the interviewee works short shift jobs and so is able to come back home at times during the day.

Deviations or modifications

The house has been fully furnished by the family. Fabric and net curtains have been fitted to bedroom and living room windows and there are openable net curtains at the kitchen window (Figure 185, Figure 186). The family have installed a prepay meter for the electricity.

Although this house is also quite full of possessions, their arrangement does not appear to be obstructing the PSV extract grilles. It is interesting to note that the position of the kitchen extract is right in the corner of the room as opposed to closer to the centre as in Carla's dwelling (C0, Figure 171), and the location of the bathroom cabinet are further away from each other than in Sarah's dwelling (C1, Figure 176), so that the residents' possessions are less able to interfere with the ventilation system components (Figure 182).

Among the various possessions kept in the house were two digital clocks which also display internal temperature readings. These were displayed in quite prominent places on the living room shelf and above the bathroom cabinet (Figure 183).

The thermostat was set to 25°C and the heating was switched on (though the programme is set for mornings and evening only and the interview took place during the daytime). A desk fan was also operating in the kitchen, where the large window was open, at the time of the interview despite the fact that average external local temperature that day was only 11°C (Figure 184). The family also have an electric heater which they used to stay warm in their previous very cold (and mouldy) home but which they now use in the garden with an extension cord on summer evenings. Other windows which were open at the time of the interview were the living room

French doors, the upstairs hallway window and the master bedroom window. The resident explained that all trickle vents were kept open at all times. The TV was also switched on during the interview as her son was watching cartoons. There is an additional fridge in the kitchen which was switched off at the time of the interview. There is a pet goldfish in a fishbowl in the kitchen (no electricity use).

Figure 182: Ceiling extract in kitchen (C2)

Figure 183: Clock and thermometer in living room (left) and bathroom (right) (C2)

Figure 184: Thermostat set to 25°C (left), electric fan in kitchen (left) and spare electric heater in cupboard (right) (C2)

Figure 185: Open windows in living room (left), kitchen (centre) and upstairs hallway (right) (C2)

Figure 186: Net and fabric curtains in master bedroom (left), son's bedroom (right) (C2)

Dwelling C3

The resident (Joy)

Joy was interviewed on the afternoon of 03/05/13. She had lived at the mid-terrace property with her husband and four children for about 4 years at the time of the interview. Joy's husband has mobility problems and they live in one of the larger houses (type 4) which has an internal lift. Joy works nights and the younger children attend school. The house is rented from the RSL. The front of the house faces south-west and the rear elevation and garden face north-east. Several of the children were present at the time of the interview as well as two of their own children (Joy's grandchildren). Other members of the family and some visitors were in the kitchen.

Deviations or modifications

The house has been furnished by the residents and was full of furniture, a large television and sound system, clothes and other possessions (Figure 187, Figure 188). Net and fabric curtains have been fitted to all the windows and as many of these were closed the house felt dark inside compared to the bright daylight outside (Figure 189). An energy monitor was prominently displayed in the entrance hallway (Figure 190).

Although there were several open windows during the interview (kitchen, top floor landing and master bedroom), the house felt warm and a little stuffy. The heating system was switched off. The average local temperature that day was 13.7°C; however, it was sunny and felt much warmer at times. There was a freestanding electric fan on first floor landing and smaller desk fan in the front bedroom (Figure 191).

Figure 187: Drying clothes on heated rail in second floor bathroom (left) and radiator (right) (C3)

Figure 188: Ceiling extracts in kitchen (left) and utility room (right) (C3)

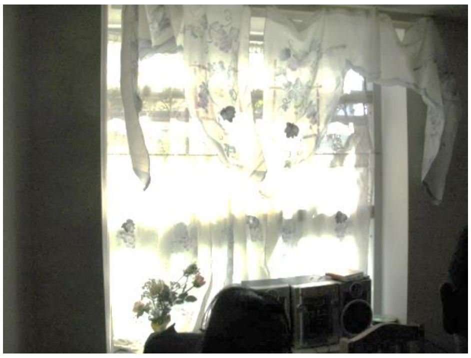


Figure 189: Kitchen curtains (C3)

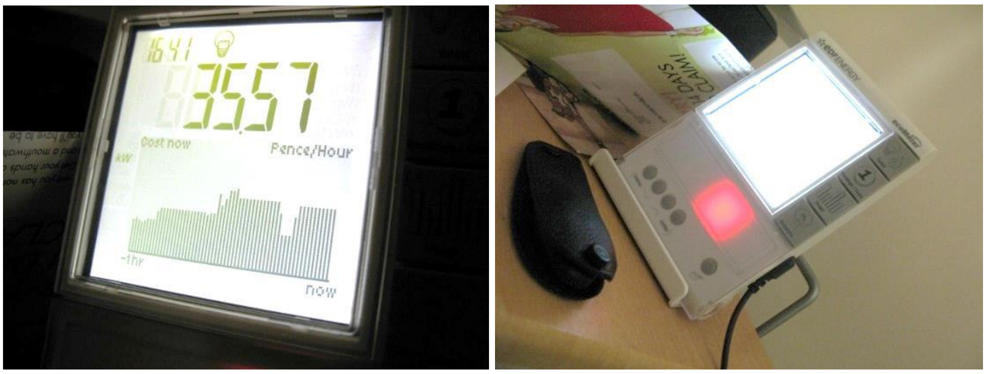


Figure 190: Energy monitor in hallway (C3)

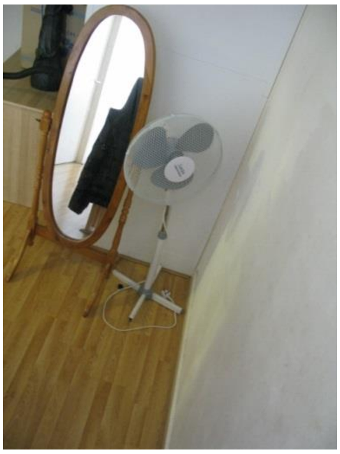


Figure 191: Freestanding fan on first floor landing (C3)

Appendix D. INFORMATION ABOUT VENTILATION PROVIDED IN THE O&M AND USER MANUALS

Case A

Manual at time of handover to existing residents

Tenant's information

We have designed and built your new home to -

- improve your comfort and convenience
- reduce your gas and electricity bills and reduce harmful greenhouse gas emissions
- reduce your water bill and conserve water
- ensure that it is secure.

Your home has high levels of insulation in the floor, roof and walls, triple glazed windows. In addition, it has a high efficiency condensing gas boiler and low energy light bulbs to reduce energy consumption. Your house is designed to reduce air leakage through the construction and the hall is designed to reduce cold draughts when you open the front door. The usual cold loft is eliminated to provide additional space and light. Good size windows reduce the need for artificial lighting and a controlled ventilation system is provided.

The WCs and taps are designed to use less water, a shower is provided which uses about one quarter of the water needed to have a bath. A water butt is provided for watering the back garden.

The materials used to construct your new home have been selected to reduce the amount of energy used and pollution created in their manufacture. The structure is timber. This is instead of using brick and concrete block with cement mortar all of which require substantial energy to manufacture. Similarly, the walls, ground floor and roof are insulated with cellulose fibre made from recycled newspaper.

Natural building materials are used and paints and varnishes are specified to reduce potential risks to health from chemicals given off into the air.

Heating system

- The heating system is designed to be very efficient.
- The gas boiler is a combination boiler which provides instantaneous hot water for the taps as well as for heating. It is a high efficiency combination boiler. Set the central heating control to a low temperature for maximum efficiency. Set the hot water control to 'ECO' which is 55 degrees C for maximum economy and normal use.
- The system is controlled by a room thermostat in the dining area. This is used to set when the heating comes on and off and to set the temperature. Keep the temperature as low as is comfortable to reduce energy consumption and gas bills. The maximum temperature in the living room would normally be 21 degrees C and 18 in the bedrooms.
- The radiators are fitted with thermostatic radiator valves which control the temperature in each room. Again set as low as is comfortable to reduce energy consumption. A setting of 3 should normally achieve a comfortable temperature.

Hot & cold water

- The system is a mains pressure system. This provides good balanced pressure for the shower. There is no water storage tank.
- The water meter is in the pavement in front of your house.
- The water into the house can be turned off in an emergency with a lever valve in the duct below the shower room window. Lift the top off the duct to gain access to this valve and to the WC cistern.
- Connections for a washing machine are provided below the sink. It is vitally important that the hot and cold water and waste connections do not leak.

Figure 192: Tenant's information, p1 (Case A)

Electrical

- The electrical system is designed to reduce energy consumption and uses low energy lamps as follows –
  - Pendant fittings in ground floor living room and dining area and batten fitting in cupboard under stairs : PLC 18w 4 pin
  - Wall lights first floor : PLC 18w 2 pin
  - Downlights in kitchen, stairs and bedrooms PLT 18w 4 pin
  - External lights : 26w 2pin
  - Shaverlights : PLS 11w 2 pin
  - Bathroom wall light : 2D 28w 4pin
- Whilst these cost more than a standard lamp, as well as using one quarter of the energy, they last 10 times longer and save money in the long run.
- The pendant lights take the continental size of lampshade which has a 40mm diameter ring. These are obtainable from Ikea and other stores or can be ordered from Lampholder 2000 on 01 536 520 101 or www.lampholder.co.uk. Adaptors are supplied for modifying a standard lampshade to fit.
- The meter is in the meter cupboard outside below the shower room window.
- The main isolating switch, RCD (Residual Current Device) and MCB's (Miniature Circuit Breakers) are all in the cabinet built into the lobby wall by the front door. These replace fuses with fuse wire and are far safer to use. The main switch will turn off the whole electrical system. The power circuits are protected by a RCD. The individual electrical circuits are isolated by individual MCB's. When a fault occurs, the RCD or MCB can be simply turned back on when the fault is cleared. If either the RCD or a MCB trips off, the procedure for resetting is –
  - Attempt to reset
  - If it trips again, switch off or unplug all equipment on the circuit.
  - Reset the device. Switch on or plug in each item of equipment in turn until the device trips again. This will be the faulty equipment and should be unplugged or turned off and help sought. If the device cannot be reset after isolating all equipment, report to Greenoak Housing Association.
- The impact of using electricity on the environment is reduced because your supply is from Ecotricity who are a 'green' supplier. They generate power from renewable sources currently mainly from the wind. This green supply is no more expensive than the standard polluting tariff. You can find information about green electricity suppliers on www.greenelectricity.org.
- The house is provided with a smoke alarm on the top landing and a heat alarm in the kitchen. These are important for your safety and must not be covered or otherwise tampered with

Appliances

- In a low-energy house, the principle use of energy and source of emissions is the appliances, the fridge, freezer and washing machine. If you are buying a new fridge, freezer or washing machine make sure that it is A or AA rated under the EU Energy labelling scheme. The performance of different makes can be seen on the Energy Saving Trust website on www.est.org.uk/myhome.
- A significant amount of power is consumed by appliances such as the television or hi-fi being left on standby Turn everything off when you are not using it.

Figure 193: Tenant's information, p2 (Case A)

Ventilation

- Your house is fitted with a controlled ventilation system which provides fresh air continuously day and night. The system extracts moist air from the kitchen, shower room and bathroom. The other rooms, living room and bedroom have fresh air inlets in the wall. The
- system is controlled automatically by humidity sensitive valves so that the system extracts more air if you are cooking or having a bath or shower. It also lets in less fresh air if a room is unoccupied. There is a switch in the kitchen, which allows you to boost the extract rate in the kitchen to remove cooking smells. The inlets and outlets should be kept clean and unobstructed.

Gas

- There is a gas supply to the boiler and cooker. The meter and isolating valve are in a cabinet inside the meter cupboard at the front of the house.

Cooking

- Using gas for cooking leads to far less pollution than using electricity as electricity creates pollution at the power station.
- If you have a gas cooker, this will have to be connected to the gas supply by a CORGI registered fitter; your cooker supplier of the local British Gas showroom should be able to arrange this. The electrical connection behind the cooker can be changed to a fused spur if you need a mains supply for gas ignition.
- If you have an electric cooker, this will have to be wired into the outlet in the cooker space by a competent electrician.

Television

- Your house is provided with a television service which will receive the 5 terrestrial channels. Outlets are positioned in the living room and one bedroom upstairs.
- There is no provision for cable TV at present but you can pay for this to be put in if you wish. **Please contact the [redacted] office before making arrangements as under no circumstances should the fabric of the building be damaged.**
- The system as installed will receive digital TV and radio if you purchase the set-top box.
- Your house is wired for satellite TV but a communal dish receiver will only be fitted as and when the residents request it. A service charge may be required.

Telephone

- The house is ready wired for telephone. Points are provided in the living room, dining room and bedrooms. You will need to arrange for a telephone service to be connected to your house. The telephone entry position is in the meter cupboard.

Intruder alarm

- A separate un-switched power supply is provided in the cupboard under the stair for a burglar alarm to be fitted.

Please contact the [redacted] office before making arrangements as under no circumstances should the fabric of the building be damaged.

Internal finishes

- The internal finishes are designed to reduce their impact on the environment.
- The linoleum should not require any regular maintenance but if it requires renovation in heavily trafficked areas it can be treated with an emulsion polish, ‘Monel’ by Forbo Ltd 01 592 643 777 or similar product.

[redacted]

Figure 194: Tenant’s information, p3 (Case A)

- The internal woodwork is treated with 'Wood Wax Clear', the doors with 'Wood Wax Opaque' colour ref Blue 3152 and the floor with 'Prolyx Oil' all by Osmo Ltd and obtainable [redacted] walls and ceilings are painted with emulsion paint by Natural Building Products 01 844 338 338 white on the ceilings, Vanilla, Ochre or Terracotta on the walls. This paint can also be obtained from [redacted] as above.

External finishes

- The exterior of the building is designed to require very little maintenance. The windows have an aluminium cladding, the render and **timber is left in its natural colour none of which should be painted in any way.**
- It is important to make sure that the ventilation slot around the bottom of the building remains clear of leaves, earth and any other obstruction because the timber structure requires ventilation.

Recycling

- A segregated waste bin is provided in the kitchen to store paper, glass, kitchen waste for composting and other recycled rubbish.
- The council provide a blue bin for recycled waste; paper, card, plastics and tin. They also provide a grey wheelie bin for the remaining refuse which cannot be recycled. **Collections are on Mondays.**
- Vegetable waste can be composted and used to improve the soil in the garden. Compost bins can be obtained for £16.95 with free delivery from www.getcomposting.com/woking/

Fixings

- The walls are made of plasterboard fixed to 50mm wide vertical timber battens which are generally spaced every 600mm apart. **Normal screw fixings can be made into these battens but you have to be careful to locate the battens first. This can generally be done by tapping the wall.** Cavity fixings which come in a number of forms have to be used elsewhere.
- There is plywood behind the plasterboard in the bathroom and shower room so that support rails can be securely fixed if necessary.
- Curtain rails or blinds are best fixed to the underside of the timber lining at the top of the windows although it would be possible to fix them to the wall immediately above the windows where there is timber behind the plasterboard.

Landscaping

- There is a hedge planted between back gardens and in the front garden. **Please make sure that this and other planting and turf is kept watered during dry weather for the first growing season.**

Residents' Involvement

- We are keen to involve you in matters relating to your houses and we will be organising a meeting of residents as soon as possible.

Contacts

[redacted] ders concerning any problems.
Gas leaks emergency number is 0800 111 999

[redacted]

Figure 195: Tenant's information, p4 (Case A)

Information pack revised in 2013 for new residents

INFORMATION ABOUT YOUR HOME

Introduction

We hope you enjoy your home! It was built with a number of features to -

- Improve comfort, convenience and accessibility
- Reduce your gas and electricity bills and reduce harmful greenhouse gases
- Reduce your water bill and conserve water
- Provide good indoor air quality and reduce pollution
- Ensure that it is secure.

In this introduction we will tell you a bit more about the things that make this house different from other houses you have lived in. After that we list out how all the features of your house work in detail.

ENERGY SAVING

Your home is very energy efficient. The high levels of insulation in the floor, roof and walls, and triple-glazed windows reduce the need for heating for most of the year. The entrance lobby is designed to reduce cold draughts; it is a buffer between the front door and your living areas. The high efficiency gas boiler provides heating and hot water. Low energy light bulbs are fitted to reduce electricity consumption. Good size windows reduce the need for artificial lighting and a whole house ventilation system is built-in to ensure fresh air.

Your house uses a fraction of the energy used by typical UK houses and is built much better than the current building regulations require for new homes. However, how much you save also depends on your usage! Some general tips:

- **To reduce gas use for heating**:
  - Use the timers on your heating thermostat, keep windows closed when the heating is on, and only heat the house when needed.
- **To reduce gas use for hot water**:
  - Use showers instead of baths and keep shower times short.
  - Wash up in a bowl rather than under a hot running tap. This will reduce the amount of gas needed to heat up the water, as well as reduce the amount of water used.
- **To reduce electricity use**:
  - Turn off electrical appliances at the switch when not in use. Especially TVs, Sky or Virgin boxes and game consoles can use up a lot of electricity even when on standby.
  - Turn off lights if there is enough daylight and whenever leaving a room.

WATER SAVING

All new houses have metered water supplies which means you can check your water consumption and get rewarded for saving water by means of lower water bills! The house helps you along with this in the following ways:

- Toilets, taps and showerheads are specially designed to work efficiently with less water.
- A shower is provided which uses about one quarter of the water needed to have a bath.
- Externally a water butt is provided for watering the back garden.

You can further save money by not wasting water or letting taps run and reporting any leaks or problems immediately.

1

Figure 196: Tenant's information, revised 2013, p1 (Case A)

Tip: You can contact [redacted] and ask for Green Doctor support to help you utilise your house better and reduce energy consumption, which means you pay less for your gas, electricity and water bills.

AIR AND POLLUTION

The materials used to construct your new home have been selected to reduce the amount of energy used and pollution created in their manufacture. One main example is that the structure is made of timber instead of brick and concrete block.

Natural building materials, paints and varnishes, for example, have been used to reduce any potential risks to health from chemicals given off into the air. We would encourage you to continue using these in future to keep the house free of toxins.

The house is built in such a way that air leakage through the construction is greatly reduced. However, fresh air is important so a special ventilation system is fitted to provide constant fresh air everywhere in the house whilst extracting stale moist air from kitchen and bathroom.

SECURITY

The houses have been approved by the Police to achieve the ‘Secured by Design’ standard, which incorporates the design and quality of windows, doors, locks, and layout of the scheme. For instance the glass is laminated and doors have multi-point locking.

CONVENIENCE

Your home has been designed to meet the “Lifetime Homes” standard. They can be adapted to suit the needs of people with mobility problems. Examples are level access and convenient socket heights. Furthermore, allowance has been made for a ground floor shower and a through-floor lift to be easily installed if and when required.

If any member of your household should have any special needs, or you wish to alter anything in your house then please contact us. We can then advise you of the possibilities.

Heating system

- The high efficiency gas boiler is a combination boiler, which provides instantaneous hot water for the taps as well as for heating without the need for a hot water tank. The settings on the boiler should be: Central Heating to ‘MAX’ and Hot Water on ‘ECO’
- A programmable room thermostat in the living area controls the system. This is used to set when the heating comes on and off and to set the temperature. Especially when not in the house during the day, ensure that the heating is turned low. Keep the temperature as low as is comfortable to reduce energy consumption and gas bills. The usual temperature in the living room would be 21 degrees C. Consult your thermostat user guide for guidance on how to change the settings. If you would like help with this, please do not hesitate to contact our Green Doctor team.
- All radiators are fitted with thermostatic radiator valves, which control the temperature in each room. Again set as low as is comfortable to reduce energy consumption or turn off completely, for example upstairs.

Hot & cold water

- The system is a mains pressure system, which provides good balanced pressure for the shower. There is no water storage tank.

[redacted] 2

Figure 197: Tenant’s information, revised 2013, p2 (Case A)

- The water meter is in the pavement in front of your house.
- The water into the house can be turned off in an emergency with a lever valve in the duct below the shower room window. Lift the top off the duct to gain access to this valve and to the WC cistern.
- Connections for a washing machine are provided below the sink. It is vitally important that the hot and cold water and waste connections do not leak.

Electrical

- The meter is in the meter cupboard outside, next to your front door.
- The main isolating switch, RCD (Residual Current Device) and MCB's (Miniature Circuit Breakers) are all in the cabinet built into the lobby wall by the front door. These replace fuses and are far safer to use. The main switch will turn off the whole electrical system in an emergency. The power circuits are protected by a RCD that protects against fatal shock and will not allow any faulty equipment to be plugged in and switched on. The individual electrical circuits are isolated by individual MCB's. When a fault occurs, the RCD or MCB can be simply turned back on when the fault is cleared.
- If either the RCD or a MCB trips off, the procedure for resetting is –
  - attempt to reset
  - if it trips again, switch off or unplug all equipment on the circuit(s).
  - Reset the device. Switch on or plug in each item of equipment in turn until the device trips again. This will be the faulty equipment and should be unplugged or turned off and help sought. If the device cannot be reset after isolating all equipment, report the problem to Greenoak Housing Association.
- When your house was first let [redacted] chose Ecotricity who are a 'green' supplier. They generate power from renewable sources such as wind and solar. You can find out more about green electricity suppliers on www.greenelectricity.org. Please note that it is possible that previous tenants have changed electricity supply to another supplier. You can find out which supplier is currently providing your electricity by calling 0845 601 5467.
- A separate un-switched power supply is provided in the cupboard under the stair to allow a burglar alarm to be fitted. This could be altered for use by other appliances on request.

Lighting

- The electrical system is designed to reduce energy consumption and uses low energy light bulbs as follows
  - Pendant fittings in ground floor living room and dining area and batten fitting in cupboard under stairs : PLC 18w 4 pin
  - Wall lights first floor : PLC 18w 2 pin
  - Downlights in kitchen, stairs and bedrooms: PLT 18w 4 pin
  - External lights: 26w 2 pin
  - Shaverlight: PLS 11 w 2 pin
  - Bathroom wall light : 2D 28w 4pin

- Whilst these cost more than a standard lamp, as well as using less than one quarter of the energy, they last 10 times longer: One light bulb alone can save you up to £80 over the life time of the bulb!
- The light bulbs can be purchased locally from: WF Electrical or [redacted]
- The pendant lights take the continental size of lampshade, which has a 40mm diameter ring. These are obtainable from Ikea, Argos and other stores or can be ordered from Lampholder on 01536 713642 or www.lampholder.co.uk. Adaptors are supplied for modifying a standard lampshade to fit.

Appliances

- In a low-energy house, the main use of energy are the appliances that you plug in! When you are buying a new fridge, freezer , washing machine or other appliance make sure that it is A or AA rated under the EU Energy labelling scheme. Use the appliance only when needed and use it efficiently. For example:

[redacted] 3

Figure 198: Tenant's information, revised 2013, p3 (Case A)

- Only wash dishwasher or washing machine with a full load
- Only use the tumble drier in winter – use the washing line outside whenever possible

- The performance of different makes can be seen on the Energy Saving Trust website on www.energysavingtrust.org.uk/Electricity.
- Appliances that have a standby function consume a significant amount of power: Every brand is different but below are a few approximates:
  - TV: £20 per year
  - Digital (Sky/Virgin etc) : £25 per year
  - Microwave (clock) : £5 per year

  So please turn everything off if you are not using it!

Ventilation

- Your house is fitted with a controlled ventilation system, which provides fresh air continuously day and night. The system extracts moist air from the kitchen, shower room and bathroom. The other rooms, living room and bedrooms have fresh air inlets in the wall.
- The system is controlled automatically by humidity sensitive valves so that the system extracts more air if you are cooking or having a bath or shower.
- There is a switch in the kitchen, which allows you to boost the ventilation when cooking. Pressing this button will boost the extraction for about 20 minutes after which it returns to normal setting.
- The inlets and outlets should be kept clean and unobstructed in order to work properly and maintain a healthy air quality.
- In winter there is no need to open windows. Please ensure the ventilation system is always on and working, especially in winter. Report any concerns you might have to the maintenance team. Things like mould, humid atmosphere and a noisy system could indicate that the ventilation system is not working properly.
- Your house has a Velux window in the ceiling high above the staircase, plus another one in one bedroom. These can be opened with the long pole provided, in order to provide cooling in times of hot weather. Hot air rises and the high situated velux windows allow hot air to escape. This effect is improved if a window is opened downstairs to create a good airflow. This is best done during cooler evening time. Ensure this velux window is closed when it is raining!

Gas

- There is a gas supply to the boiler and cooker. The **meter and isolating valve** are in a cabinet outside, next to your front door. If you have just moved in and don't know who supplies your gas, you can call the Meter number helpline on 0870 608 1524

Cooking

- Using gas for cooking leads to far less pollution than using electricity, which creates pollution at the power station.
- If you are using a gas cooker, this will have to be connected to the gas supply by a "Gas-safe" registered fitter; your cooker supplier should be able to arrange this. (www.gassaferegister.co.uk) The electrical connection behind the cooker can be changed to a fused spur if you need a mains supply for gas ignition.
- If you are using an electric cooker, this will have to be wired into the outlet in the cooker space by a competent electrician.

Television

- The house is provided with a television service from a communal system, receiving the 5 terrestrial channels.
- Outlets are positioned in the living room and one bedroom upstairs.

4

Figure 199: Tenant's information, revised 2013, p4 (Case A)

- The system will receive digital TV and radio if you have the necessary set-top box. Free viewing of over 100 channels is available from FreeSat and FreeSat-from-Sky. Check out www.freesat.co.uk
- However, if you would like Sky Plus, Sky HD or Multi-Room, Sky requires an extra line. Please contact our Housing Services office for guidance.
- No external aerials or other alterations are allowed without prior written approval.

Telephone

- The house is ready wired for telephone. Points are provided in the living room and bedrooms. You will have to arrange for the telephone service to be connected to the house; the telephone entry position is in the meter cupboard.

Internal finishes

- The internal finishes are designed to reduce their impact on the environment.
- The linoleum should not require any regular maintenance but if it requires renovation in heavily trafficked areas it can be treated with an emulsion polish, 'Monel' by Forbo 0800 0935846 (www.forbo.co.uk) or similar product.
- The internal woodwork is treated with 'Wood Wax Clear', the doors with 'Wood Wax Opaque' colour ref [redacted]
- The walls and ceilings are painted with emulsion paint by Natural Building Technologies [redacted] White on the ceilings, Vanilla, Ochre or Terracotta on the walls. This paint can also be obtained from C [redacted] Ltd as above.

External finishes

- The exterior of the building is designed to require very little maintenance. The windows have an aluminium cladding, the render and timber is left in its natural colour, none of which should be painted in any way.
- It is important to make sure that the ventilation slot around the bottom of the building remains clear of leaves, earth and any other obstruction because the timber structure requires ventilation.

Recycling

- [redacted] Borough Council has an excellent recycling scheme, including paper, cardboard, glass, cans, plastics, left over food, garden waste.
- Collections are every Monday morning, with non-recyclables and garden waste collected on alternate weeks. Food Waste caddies are collected every week.
- A segregated waste bin is provided in the kitchen to store paper, glass, kitchen waste for composting and other recycled rubbish.
- The council provide a blue lidded wheelie bin for recyclables, which is a large part of what you throw away. This bin is collected every two weeks. Use it for:
  - Cardboard, paper
  - Aluminium foil, Glass bottles and jars, tins and cans (including biscuit tins)
  - Plastic bottles, tubs, trays (including yoghurt and margarine pots)
- You can also use the food waste caddy for ANY food waste, whether cooked or uncooked. Food waste is collected EVERY WEEK which means that using this food waste caddy will result in far less smells in your black wheelie bin which is only collected every two weeks. Of course you can also compost vegetable (uncooked) waste yourself and use it to improve the soil in the garden.
- The black wheelie bin can be used for anything you can not recycle and is collected every two weeks.
- For more information on recycling and refuse collection, contact [redacted] Borough Council on www [redacted]

Fixings

[redacted]

5

Figure 200: Tenant's information, revised 2013, p5 (Case A)

- The walls are made of plasterboard which is fixed to 50mm wide horizontal timber battens. These battens are generally spaced every 600mm apart. Normal screw fixings can be made into these battens but you have to be careful to locate the battens first. This can generally be done by tapping the wall. Where battens can not be used, special cavity fixings have to be used.
- There is plywood behind the plasterboard in the bathroom and shower room so that support rails can be securely fixed if necessary.
- Curtain rails or blinds are best fixed to the underside of the timber lining at the top of the windows although it would be possible to fix them to the wall immediately above the windows where there is timber behind the plasterboard. Again, tap the wall to locate the timber.

Alarms

- The house is provided with a smoke alarm on the top landing and a heat alarm in the kitchen. These are important for your safety and must not be covered or otherwise tampered with. When the back up batteries run low, an intermittent alarm will go off. You can then change the battery to resolve this. However, the alarm on the top landing is too high to reach safely. Please contact the maintenance team to change this battery.
- The house is also provided with a carbon monoxide (CO) alarm. The battery in this sealed unit can not be changed. If there is an intermittent alarm please call the maintenance team to provide you with a new alarm unit.
- A separate un-switched power supply is provided in the cupboard under the stairs for a burglar alarm to be fitted.

External

- A lockable cycle store is provided by the front door to allow the convenient use of bikes where appropriate.
- A washing line is provided in the rear garden.
- Outside lamps are controlled by movement sensors.
- Please use the water butt or re-use washing-up water when watering your plants. If you don't use the water butt please empty it as standing water can attract mosquitos.

Updated July 2013

[redacted]Association Main office: 0[redacted]

Maintenance 0

Gas leaks: National Grid Gas Emergencies number : 0800 111 999

[redacted] 6

Figure 201: Tenant's information, revised 2013, p6 (Case A)

Case B

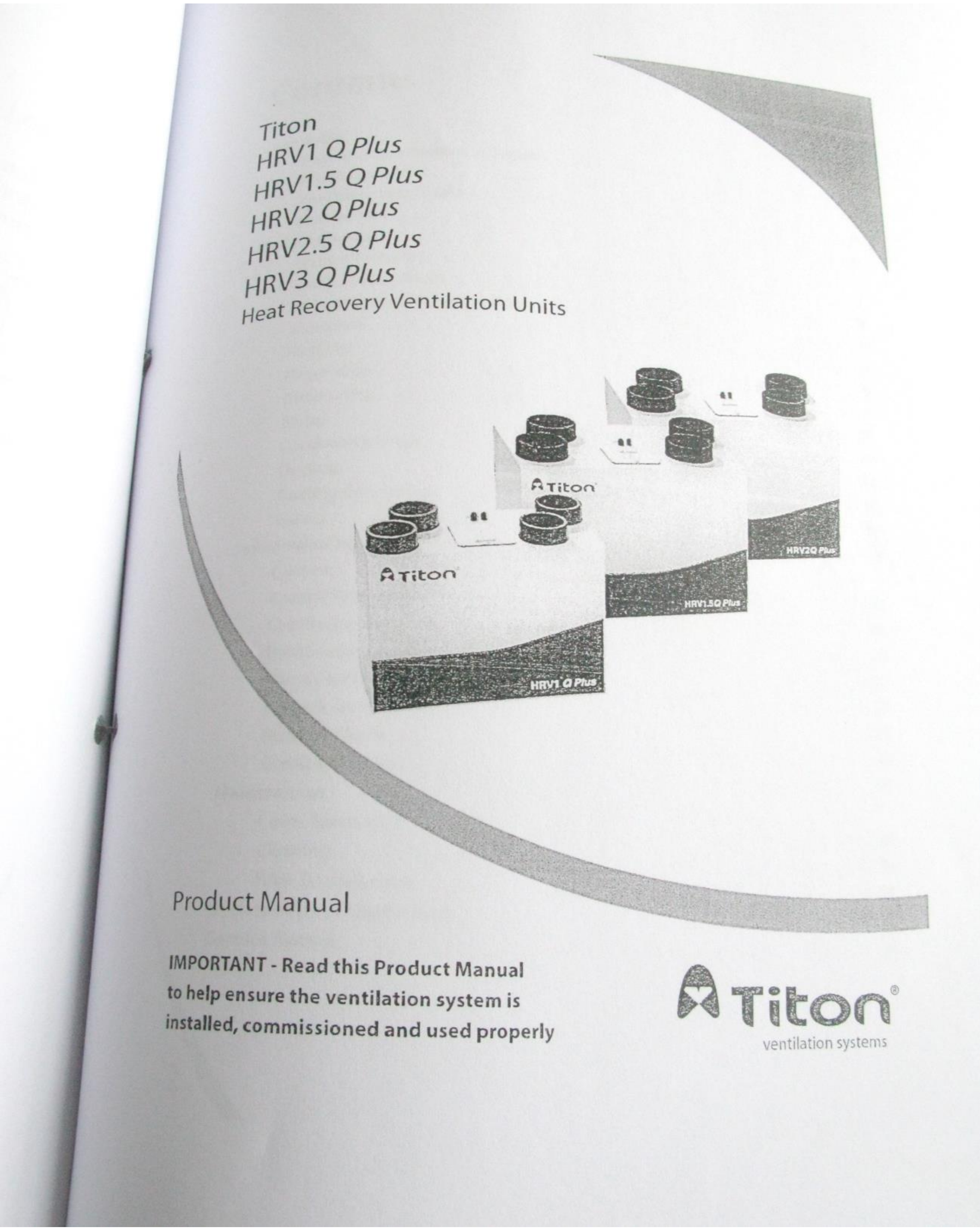
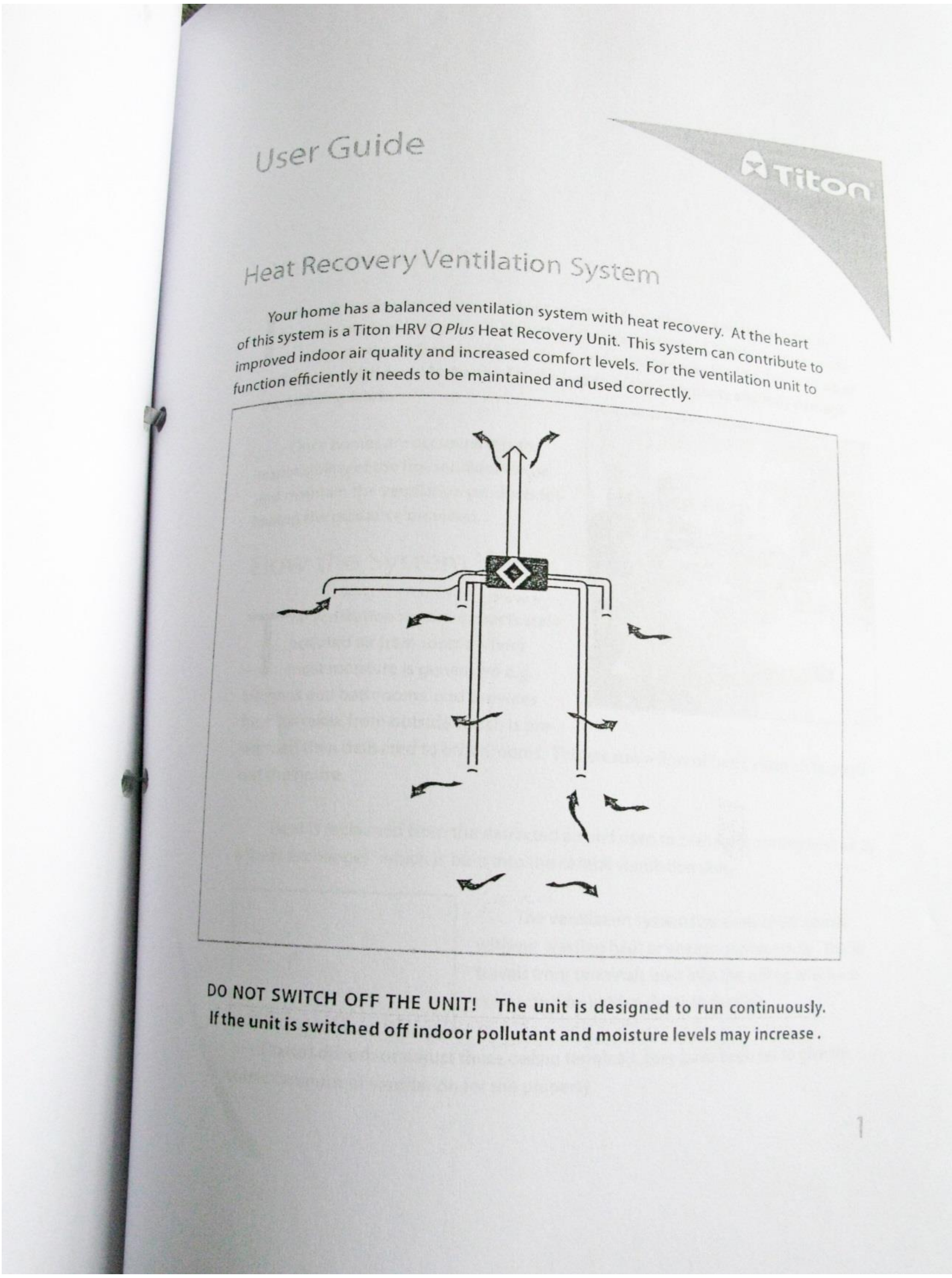


Figure 202: MVHR product manual, title page


User Guide

Titon

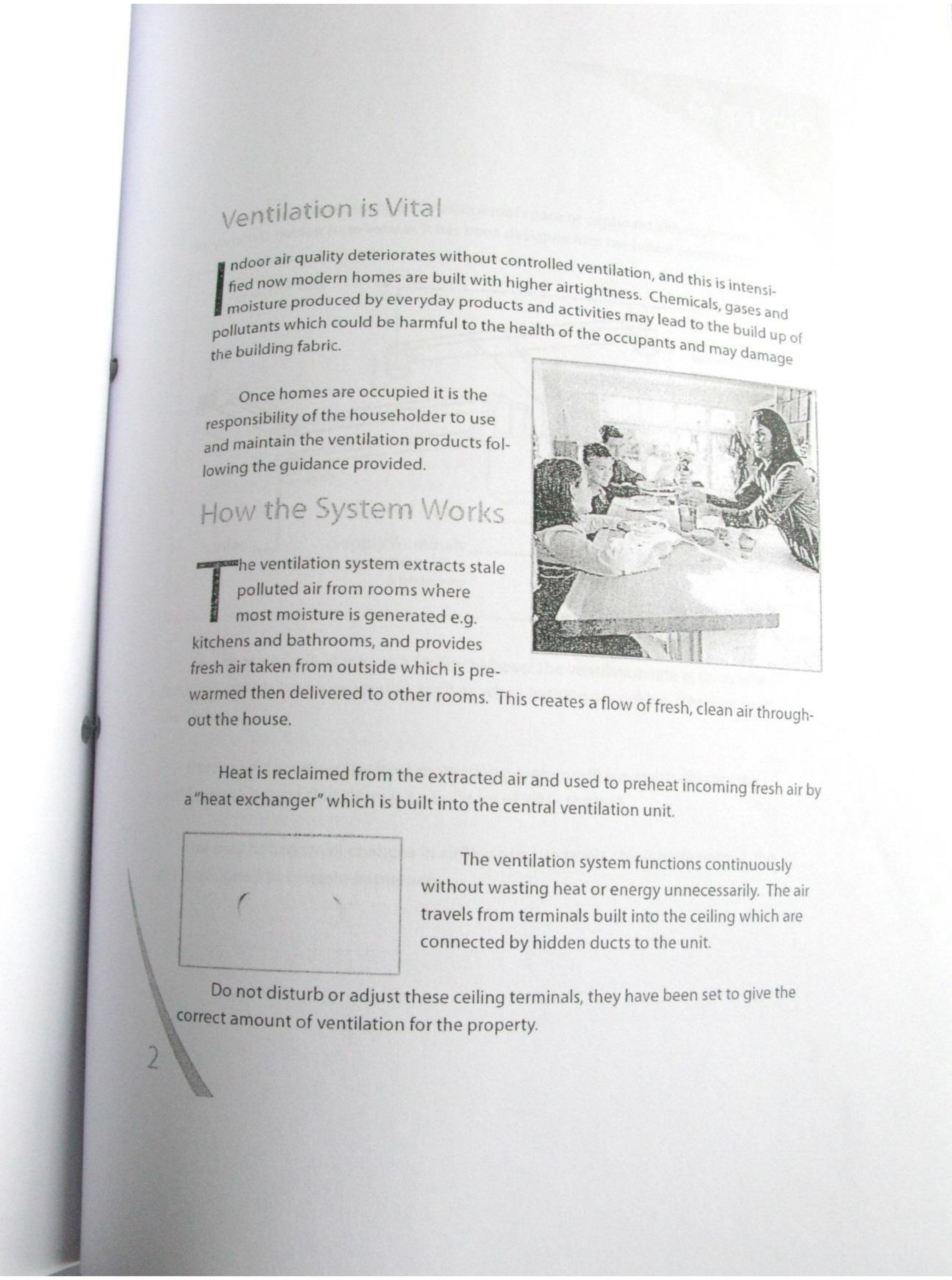
Heat Recovery Ventilation System

Your home has a balanced ventilation system with heat recovery. At the heart of this system is a Titon HRV *Q Plus* Heat Recovery Unit. This system can contribute to improved indoor air quality and increased comfort levels. For the ventilation unit to function efficiently it needs to be maintained and used correctly.

DO NOT SWITCH OFF THE UNIT! The unit is designed to run continuously. If the unit is switched off indoor pollutant and moisture levels may increase .

1

Figure 203: MVHR product manual, p1



Ventilation is Vital

Indoor air quality deteriorates without controlled ventilation, and this is intensified now modern homes are built with higher airtightness. Chemicals, gases and moisture produced by everyday products and activities may lead to the build up of pollutants which could be harmful to the health of the occupants and may damage the building fabric.

Once homes are occupied it is the responsibility of the householder to use and maintain the ventilation products following the guidance provided.

How the System Works

The ventilation system extracts stale polluted air from rooms where most moisture is generated e.g. kitchens and bathrooms, and provides fresh air taken from outside which is pre-warmed then delivered to other rooms. This creates a flow of fresh, clean air throughout the house.

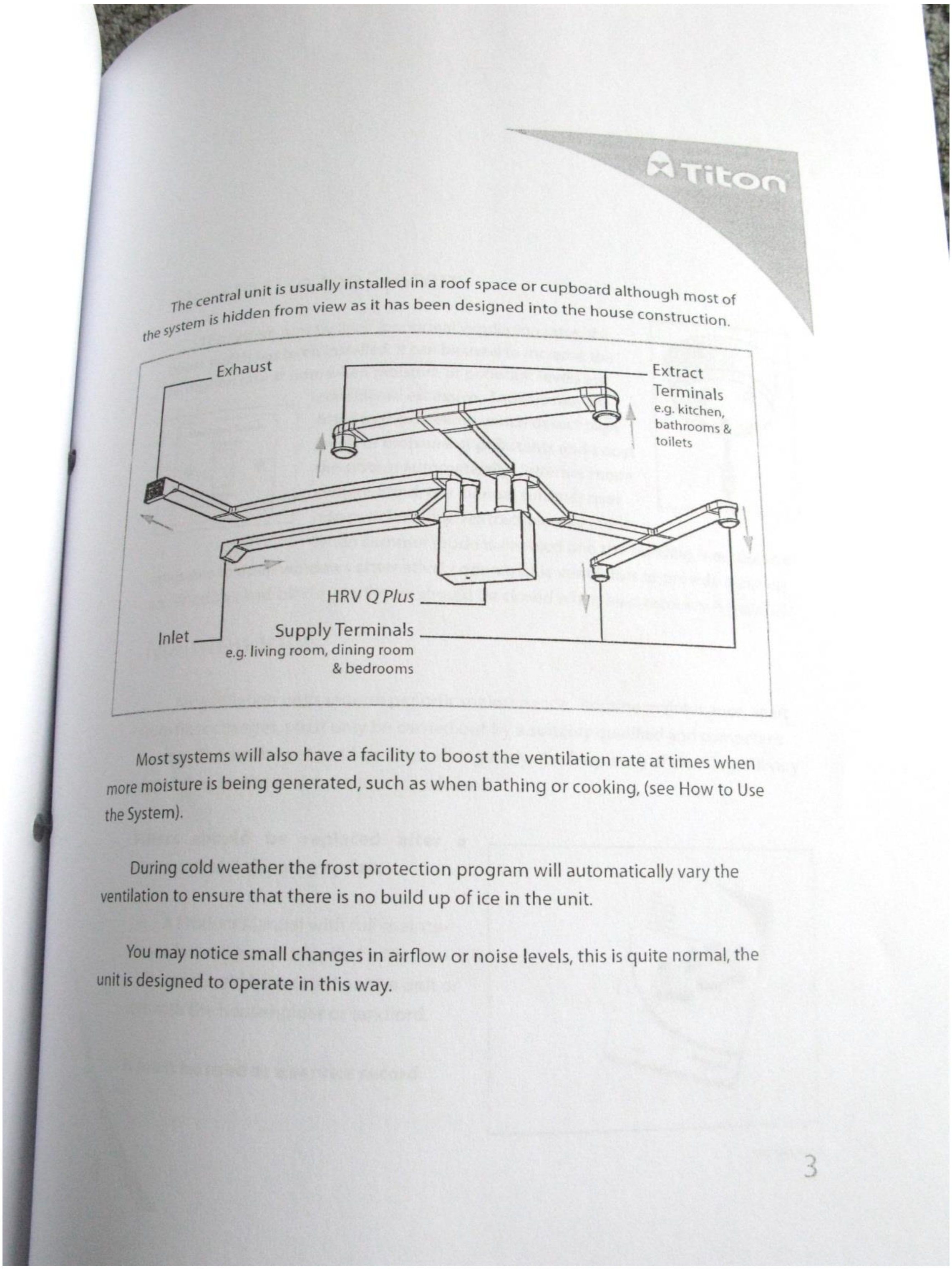
Heat is reclaimed from the extracted air and used to preheat incoming fresh air by a "heat exchanger" which is built into the central ventilation unit.

The ventilation system functions continuously without wasting heat or energy unnecessarily. The air travels from terminals built into the ceiling which are connected by hidden ducts to the unit.

Do not disturb or adjust these ceiling terminals, they have been set to give the correct amount of ventilation for the property.

2

Figure 204: MVHR product manual, p2


Titon

The central unit is usually installed in a roof space or cupboard although most of the system is hidden from view as it has been designed into the house construction.

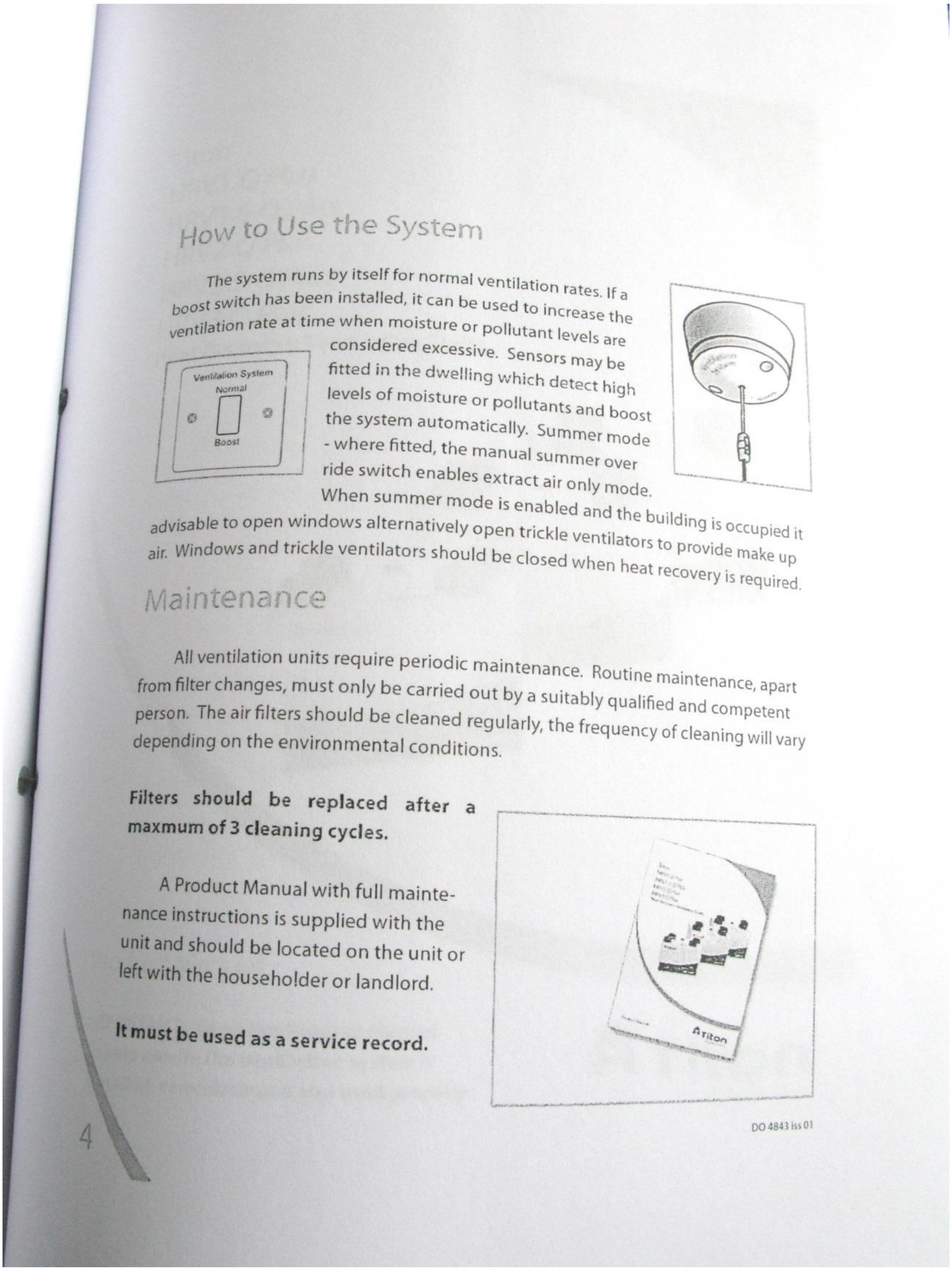
Most systems will also have a facility to boost the ventilation rate at times when more moisture is being generated, such as when bathing or cooking, (see How to Use the System).

During cold weather the frost protection program will automatically vary the ventilation to ensure that there is no build up of ice in the unit.

You may notice small changes in airflow or noise levels, this is quite normal, the unit is designed to operate in this way.

3

Figure 205: MVHR product manual, p,3



How to Use the System

The system runs by itself for normal ventilation rates. If a boost switch has been installed, it can be used to increase the ventilation rate at time when moisture or pollutant levels are considered excessive. Sensors may be fitted in the dwelling which detect high levels of moisture or pollutants and boost the system automatically. Summer mode - where fitted, the manual summer over ride switch enables extract air only mode. When summer mode is enabled and the building is occupied it advisable to open windows alternatively open trickle ventilators to provide make up air. Windows and trickle ventilators should be closed when heat recovery is required.

Ventilation System
Normal
Boost

Maintenance

All ventilation units require periodic maintenance. Routine maintenance, apart from filter changes, must only be carried out by a suitably qualified and competent person. The air filters should be cleaned regularly, the frequency of cleaning will vary depending on the environmental conditions.

Filters should be replaced after a maxmum of 3 cleaning cycles.

A Product Manual with full maintenance instructions is supplied with the unit and should be located on the unit or left with the householder or landlord.

It must be used as a service record.

4

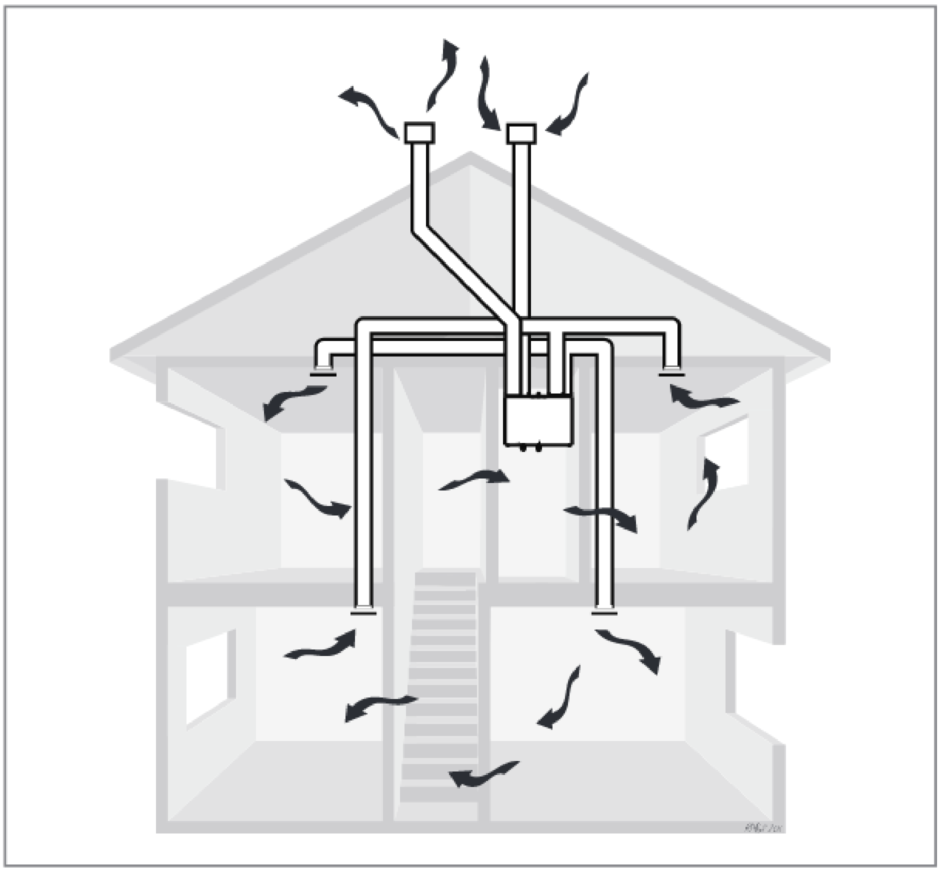
DO 4843 iss 01

Figure 206: MVHR product manual, p4

User Guide

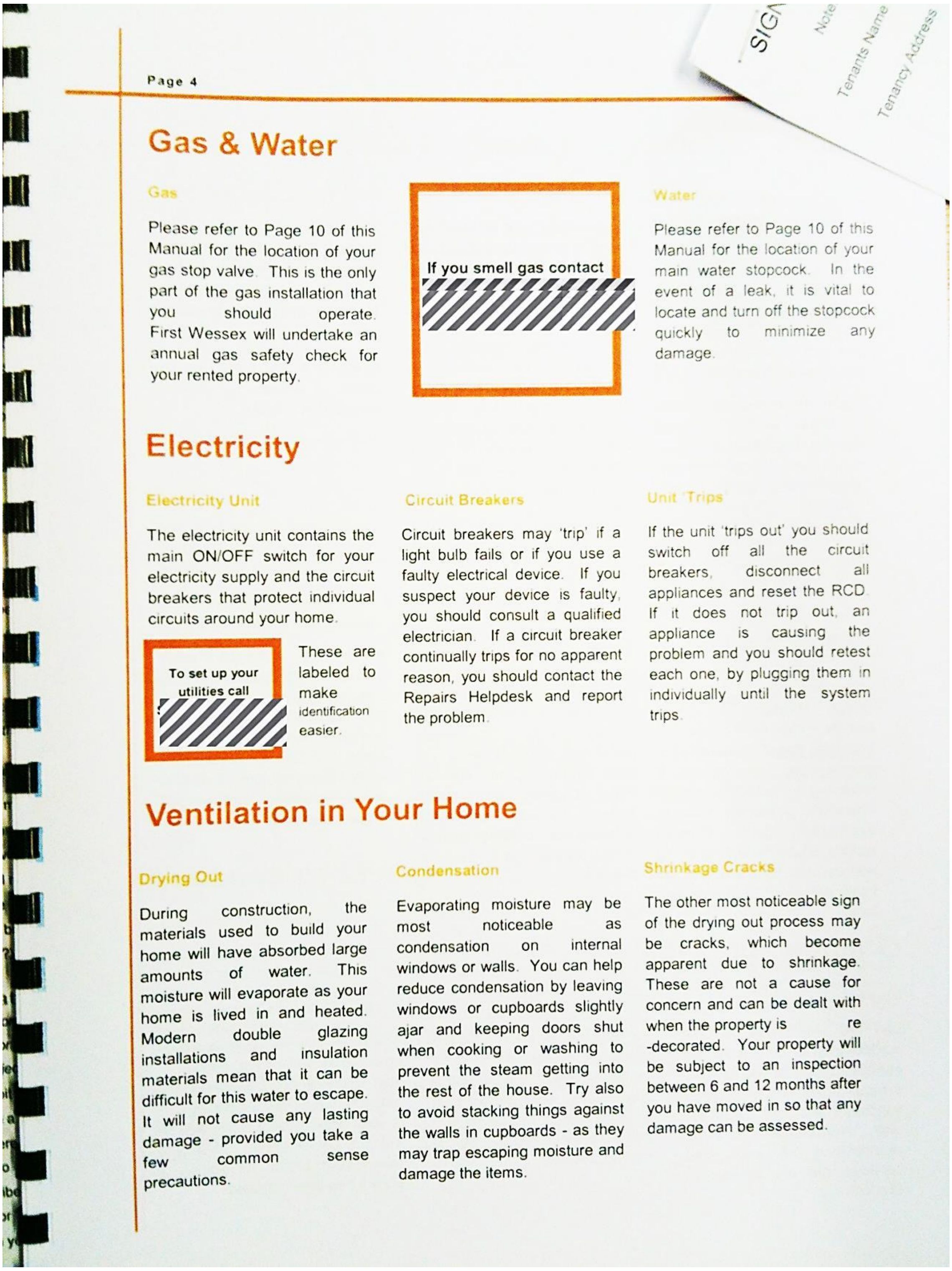
Heat Recovery Ventilation System

Your home has a balanced ventilation system with heat recovery. At the heart of this system is a Titon HRV *Q Plus* Heat Recovery Unit. This system contributes to improved indoor air quality and increased comfort levels. For the ventilation unit to function efficiently it needs to be maintained and used correctly.



DO NOT SWITCH OFF THE UNIT! The system is designed to run continuously.
If the unit is switched off indoor pollutant and moisture levels may increase.

Figure 207: Extract from 2011 version of the MVHR product manual



Page 4

Gas & Water

Gas

Please refer to Page 10 of this Manual for the location of your gas stop valve. This is the only part of the gas installation that you should operate. First Wessex will undertake an annual gas safety check for your rented property.

If you smell gas contact [redacted]

Water

Please refer to Page 10 of this Manual for the location of your main water stopcock. In the event of a leak, it is vital to locate and turn off the stopcock quickly to minimize any damage.

Electricity

Electricity Unit

The electricity unit contains the main ON/OFF switch for your electricity supply and the circuit breakers that protect individual circuits around your home.

To set up your utilities call [redacted]

These are labeled to make identification easier.

Circuit Breakers

Circuit breakers may 'trip' if a light bulb fails or if you use a faulty electrical device. If you suspect your device is faulty, you should consult a qualified electrician. If a circuit breaker continually trips for no apparent reason, you should contact the Repairs Helpdesk and report the problem.

Unit 'Trips'

If the unit 'trips out' you should switch off all the circuit breakers, disconnect all appliances and reset the RCD. If it does not trip out, an appliance is causing the problem and you should retest each one, by plugging them in individually until the system trips.

Ventilation in Your Home

Drying Out

During construction, the materials used to build your home will have absorbed large amounts of water. This moisture will evaporate as your home is lived in and heated. Modern double glazing installations and insulation materials mean that it can be difficult for this water to escape. It will not cause any lasting damage - provided you take a few common sense precautions.

Condensation

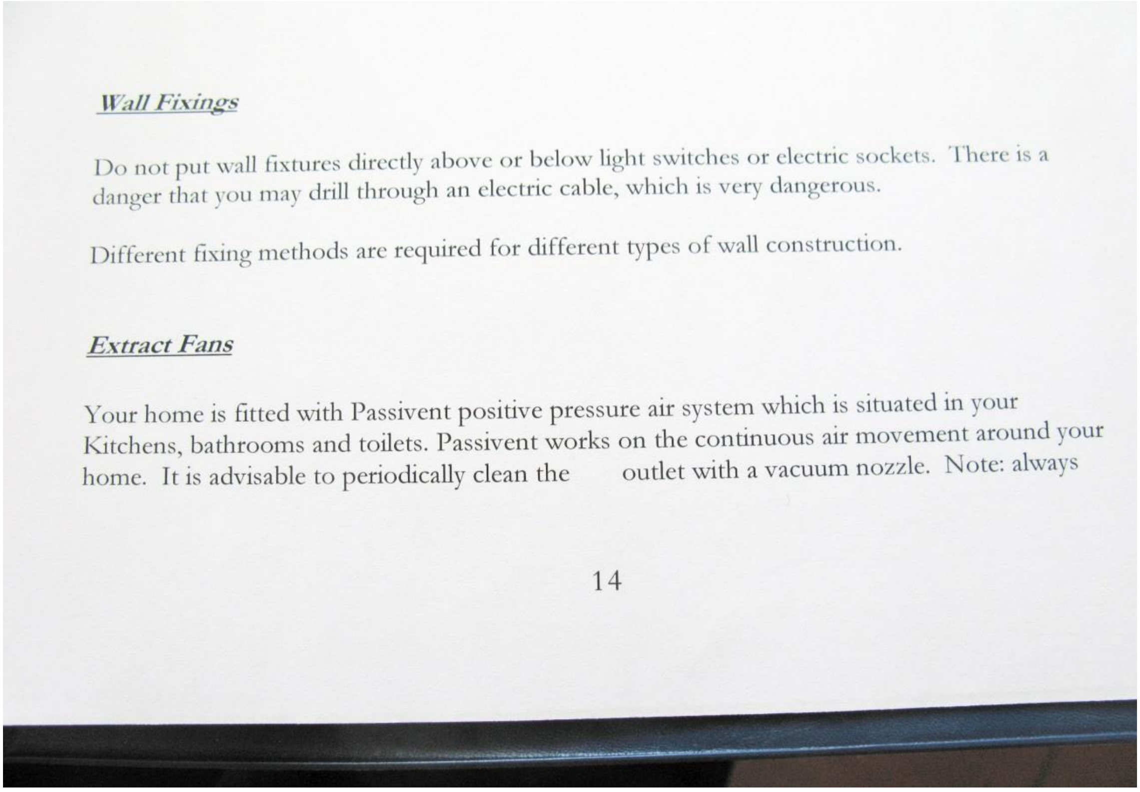
Evaporating moisture may be most noticeable as condensation on internal windows or walls. You can help reduce condensation by leaving windows or cupboards slightly ajar and keeping doors shut when cooking or washing to prevent the steam getting into the rest of the house. Try also to avoid stacking things against the walls in cupboards - as they may trap escaping moisture and damage the items.

Shrinkage Cracks

The other most noticeable sign of the drying out process may be cracks, which become apparent due to shrinkage. These are not a cause for concern and can be dealt with when the property is re-decorated. Your property will be subject to an inspection between 6 and 12 months after you have moved in so that any damage can be assessed.

Figure 208: Extract from New Homes Manual provided by RSL

Case C



Wall Fixings

Do not put wall fixtures directly above or below light switches or electric sockets. There is a danger that you may drill through an electric cable, which is very dangerous.

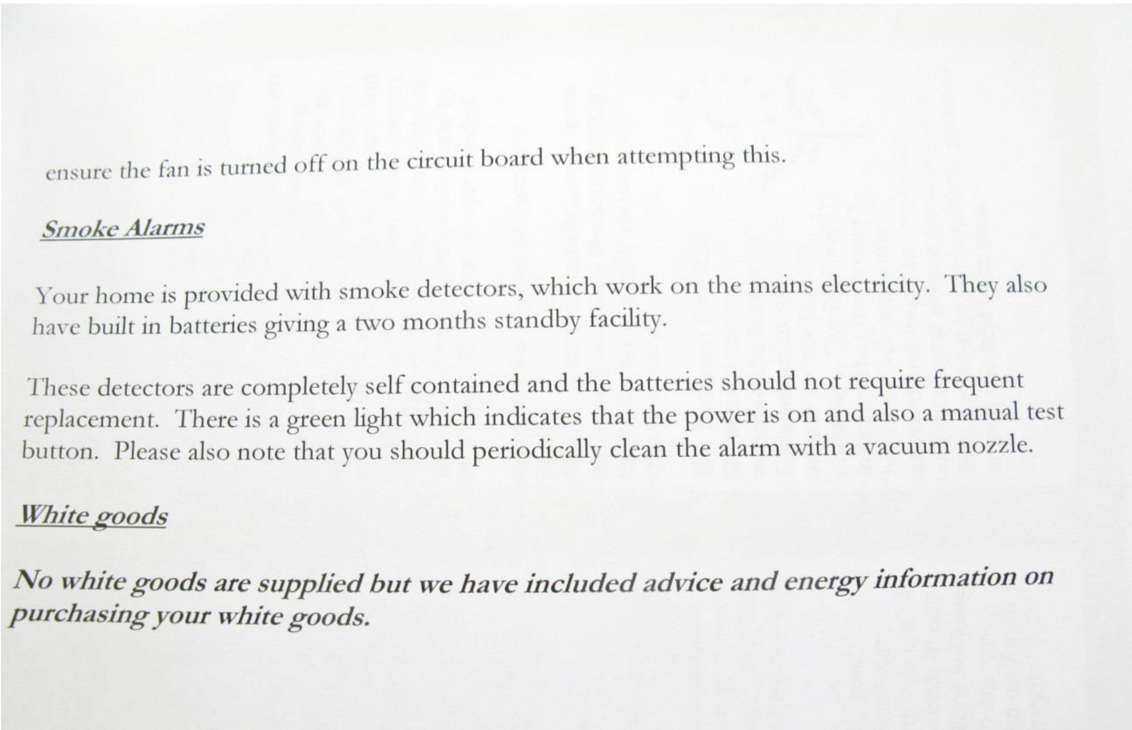
Different fixing methods are required for different types of wall construction.

Extract Fans

Your home is fitted with Passivent positive pressure air system which is situated in your Kitchens, bathrooms and toilets. Passivent works on the continuous air movement around your home. It is advisable to periodically clean the outlet with a vacuum nozzle. Note: always

14

Figure 209: Extract from user manual, p.14 (Case C)



ensure the fan is turned off on the circuit board when attempting this.

Smoke Alarms

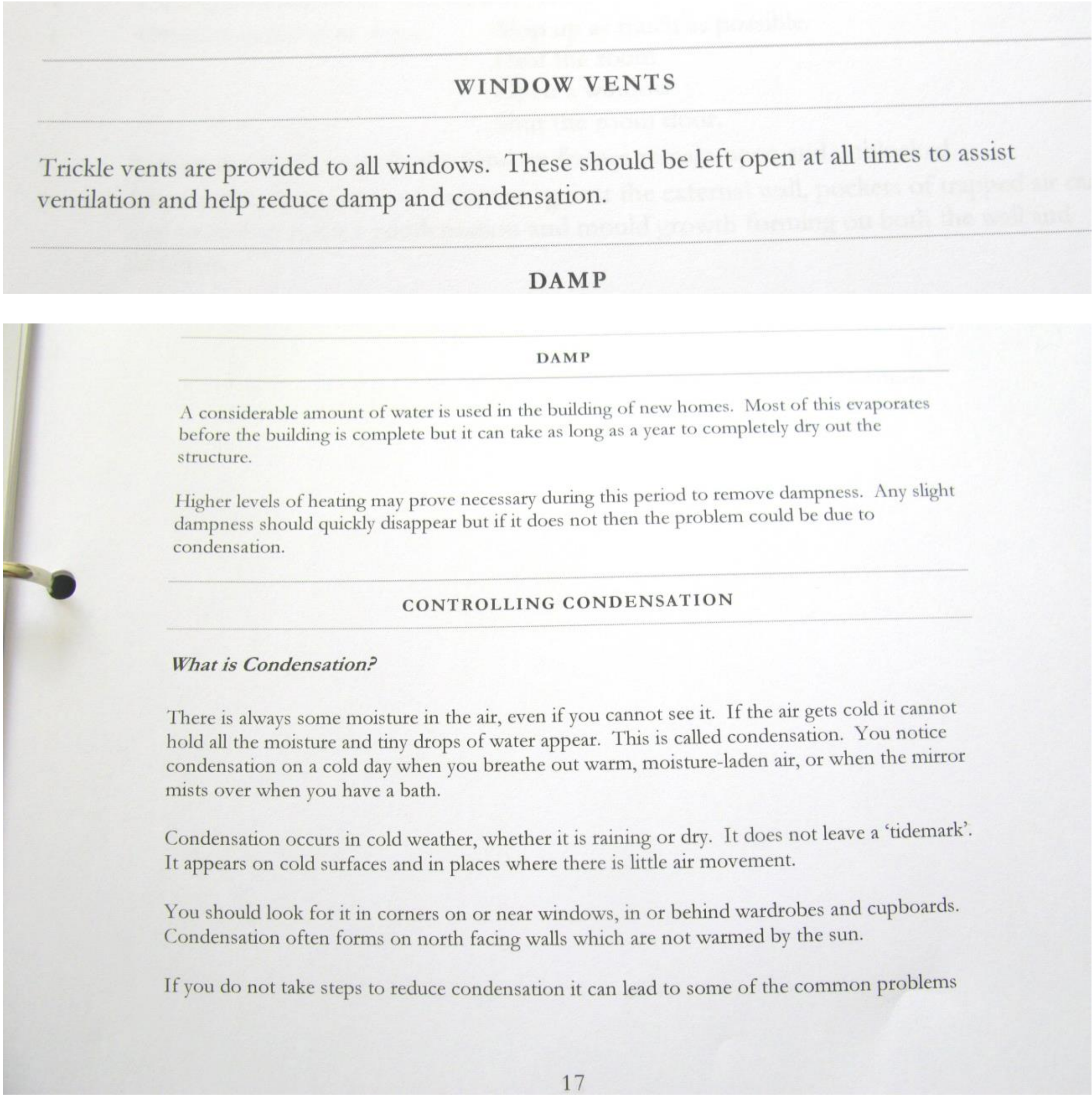
Your home is provided with smoke detectors, which work on the mains electricity. They also have built in batteries giving a two months standby facility.

These detectors are completely self contained and the batteries should not require frequent replacement. There is a green light which indicates that the power is on and also a manual test button. Please also note that you should periodically clean the alarm with a vacuum nozzle.

White goods

No white goods are supplied but we have included advice and energy information on purchasing your white goods.

Figure 210: Extract from user manual, p.15 (Case C)



WINDOW VENTS

Trickle vents are provided to all windows. These should be left open at all times to assist ventilation and help reduce damp and condensation.

DAMP

DAMP

A considerable amount of water is used in the building of new homes. Most of this evaporates before the building is complete but it can take as long as a year to completely dry out the structure.

Higher levels of heating may prove necessary during this period to remove dampness. Any slight dampness should quickly disappear but if it does not then the problem could be due to condensation.

CONTROLLING CONDENSATION

What is Condensation?

There is always some moisture in the air, even if you cannot see it. If the air gets cold it cannot hold all the moisture and tiny drops of water appear. This is called condensation. You notice condensation on a cold day when you breathe out warm, moisture-laden air, or when the mirror mists over when you have a bath.

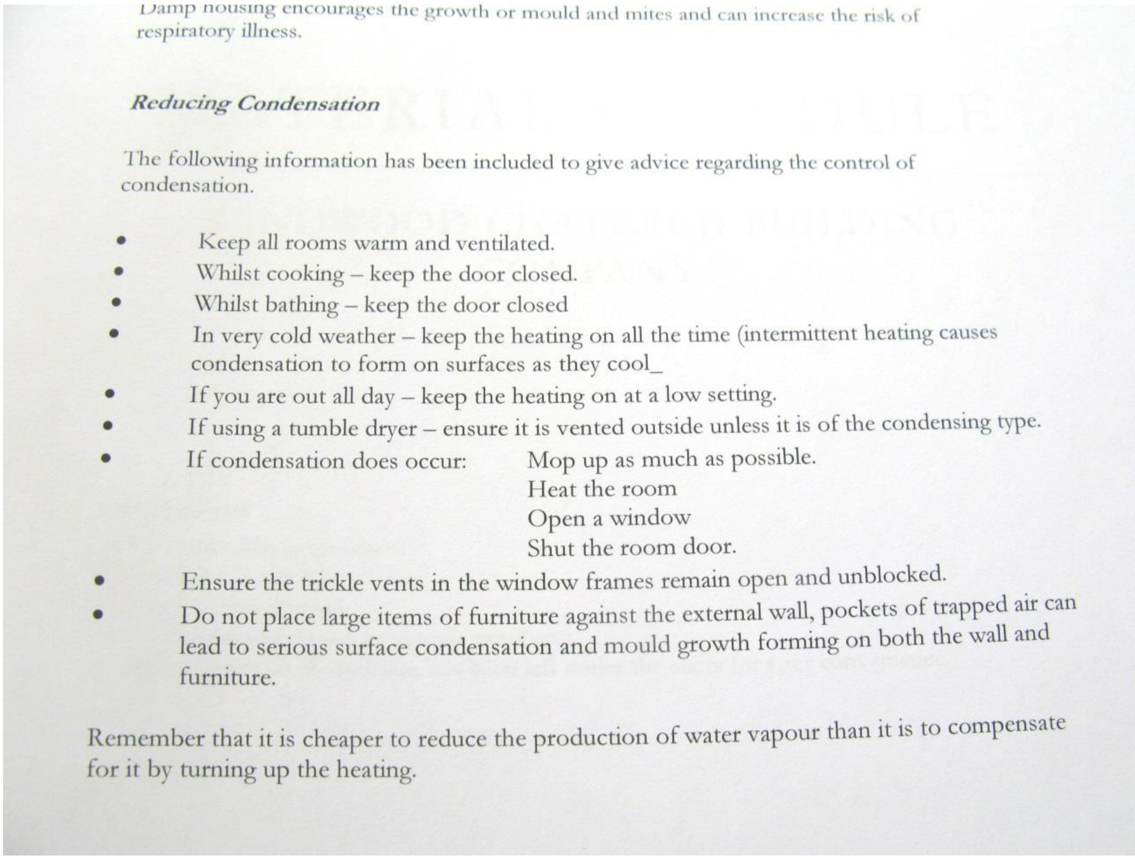
Condensation occurs in cold weather, whether it is raining or dry. It does not leave a 'tidemark'. It appears on cold surfaces and in places where there is little air movement.

You should look for it in corners on or near windows, in or behind wardrobes and cupboards. Condensation often forms on north facing walls which are not warmed by the sun.

If you do not take steps to reduce condensation it can lead to some of the common problems

17

Figure 211: Extract from user manual, p.17 (Case C)



Damp housing encourages the growth or mould and mites and can increase the risk of respiratory illness.

Reducing Condensation

The following information has been included to give advice regarding the control of condensation.

- Keep all rooms warm and ventilated.
- Whilst cooking – keep the door closed.
- Whilst bathing – keep the door closed
- In very cold weather – keep the heating on all the time (intermittent heating causes condensation to form on surfaces as they cool_
- If you are out all day – keep the heating on at a low setting.
- If using a tumble dryer – ensure it is vented outside unless it is of the condensing type.
- If condensation does occur: Mop up as much as possible.
  Heat the room
  Open a window
  Shut the room door.
- Ensure the trickle vents in the window frames remain open and unblocked.
- Do not place large items of furniture against the external wall, pockets of trapped air can lead to serious surface condensation and mould growth forming on both the wall and furniture.

Remember that it is cheaper to reduce the production of water vapour than it is to compensate for it by turning up the heating.

Figure 212: Extract from user manual, p.18 (Case C)

Appendix E. SUPPORTING MATERIAL FOR CHAPTER 2

Compliance with SAP

Compliance with SAP is calculated and demonstrated using a worksheet and data tables (BRE and DECC, 2014). Ventilation is accounted for in terms of air leakage (infiltration), and assumptions about air change rate based on the type of ventilation technology, as well as by the amount of fuel used to power the ventilation systems (if any). An estimate of the ACH is required to calculate the heating load. This can be based on an air pressure test or using the calculation shown in Figure 213, below.

2. Ventilation rate

	main heating		secondary heating		other		total		m³ per hour	
Number of chimneys		+		+		=		× 40 =		(6a)
Number of open flues		+		+		=		× 20 =		(6b)
Number of intermittent fans								× 10 =		(7a)
Number of passive vents								× 10 =		(7b)
Number of flueless gas fires								× 40 =		(7c)

			Air changes per hour	
Infiltration due to chimneys, flues, fans, PSVs	(6a)+(6b)+(7a)+(7b)+(7c) =	÷ (5) =		(8)
If a pressurisation test has been carried out or is intended, proceed to (17), otherwise continue from (9) to (16)				
Number of storeys in the dwelling (n_s)				(9)
Additional infiltration	[(9) – 1] × 0.1 =			(10)
Structural infiltration: *0.25 for steel or timber frame or 0.35 for masonry construction* *if both types of wall are present, use the value corresponding to the greater wall area (after deducting areas of openings); if equal use 0.35*				(11)
If suspended wooden ground floor, *enter 0.2 (unsealed) or 0.1 (sealed)*, else enter 0				(12)
If no draught lobby, enter 0.05, else enter 0				(13)
Percentage of windows and doors draught proofed				(14)
Window infiltration	0.25 - [0.2 × (14) ÷ 100] =			(15)
Infiltration rate	(8) + (10) + (11) + (12) + (13) + (15) =			(16)
Air permeability value, q_{50}, expressed in cubic metres per hour per square metre of envelope area				(17)
If based on air permeability value, then (18) = [(17) ÷ 20]+(8), otherwise (18) = (16)				(18)
Air permeability value applies if a pressurisation test has been done, or a design or specified air permeability is being used				
Number of sides on which dwelling is sheltered				(19)
Shelter factor	(20) = 1 - [0.075 × (19)] =			(20)
Infiltration rate incorporating shelter factor	(21) = (18) × (20) =			(21)

Figure 213: Extract from SAP worksheet showing calculation to estimate infiltration rate (BRE and DECC, 2014)

Information also needs to be provided about chimneys, open flues, intermittent extract fans, PSV vents and flueless gas fires. Trickle vents and air bricks are excluded from the calculation. For WHV systems the following additional information is required.

- For MEV and MVHR, the calculation assumes a throughput of 0.5 changes per hour. The system's specific fan power (SPF) is required in the calculation for MEV and MVHR as well as whether rigid or flexible ducting is used.
- For MVHR the efficiency of the heat exchanger and whether the ducting is within the thermal envelope must also be stated.[204]

In-use factors are applied to MVHR and MEV to account for difference between installed performance and laboratory testing.

'In-use factors are applied in all cases to the SFP and, for MVHR systems, heat exchanger efficiency to allow for differences in practical installations compared to the laboratory test conditions that are defined for the SAP test procedure. For SFP, the in-use factor allows for additional lengths and bends compared to the optimal test configuration and for the practicalities of setting the fan speed at the optimal value for the required flow rate. For MVHR efficiency the tested result is the efficiency of the heat exchanger itself and the in-use factor allows for losses from ductwork [….] Specific fan power and heat exchange efficiency are multiplied by the appropriate in-use factor for the purposes of SAP calculations' (BRE and DECC, 2014, p.13).

Table 36: Default specific fan power for MV and heat recovery efficiency for MVHR[205]

Type of mechanical ventilation	SFP, W/(litre/sec)	Heat recovery efficiency
Mechanical extract ventilation (centralised or decentralised), or positive input ventilation from outside	0.8	-
Balanced whole house mechanical ventilation, without heat recovery	2.0	-
Balanced whole house mechanical ventilation, with heat recovery	2.0	66%

[204] Rigid ducting is preferable as there is less resistance in straight and smooth runs than in ones with bends and concertina-like profiles, so overall system efficiency is increased.
[205] These apply when the product is not listed in Appendix Q. Reproduced from BRE and DECC (2014), p.214.

Table 37: SAP In-use factors for mechanical ventilation systems[206]

In-use factors are applied to the data for mechanical ventilation systems in all cases

Type of mechanical ventilation	Approved install-ation scheme	In-use factor for Specific fan power			In-use factor for Efficiency	
		Flexible duct	Rigid duct	No duct	Uninsulated ducts	Insulated ducts [d)]
Mechanical extract ventilation, centralised [a)]	No	1.70	1.40	-	-	-
	Yes	1.60	1.30	-	-	-
Mechanical extract ventilation or positive input ventilation from outside, decentralised [a)]	No	1.45	1.30	1.15	-	-
	Yes	1.45	1.30	1.15	-	-
Balanced whole house mechanical ventilation, without heat recovery [a)]	No	1.70	1.40 [c)]	-	-	-
	Yes	1.60	1.25 [c)]	-	-	-
Balanced whole house mechanical ventilation, with heat recovery [a)]	No	1.70	1.40 [c)]	-	0.70	0.85
	Yes	1.60	1.25 [c)]	-	0.70	0.85
Default data from Table 4g (all types) [b)]		2.5			0.70	

[a)] Use these values for data from the database or from data sheets obtained from www.ncm-pcdb.org.uk/sap.
[b)] Use these values for data from Table 4g.
[c)] The values for rigid ducts also apply to semi-rigid ducts provided that the semi-rigid ducts are listed in the database.
[d)] This column applies when all ductwork is within the insulated envelope of the building even though ductwork is not itself insulated.

[206] Reproduced from BRE and DECC (2014)BRE and DECC (2014), p.214.